MATHEMATICS FOR WATER AND WASTEWATER OPERATIONS

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PREFACE

This revised edition of ***Mathematics for Water and Wastewater Operations*** is published by the Ministry of Environment and Energy, Brampton Training Centre. This edition recognizes and reflects the suggestions from previous students and instructors alike.

The Mathematics Curriculum Development committee (since 1989) consists of the following Curriculum Development and Training Officers from the Brampton Training Centre: Greg Luck, Brock Paterson and Marleen West.

Editing and incorporating technical changes for this edition was done by Greg Luck. Marleen West contributed significantly to Section "J" . Brock Paterson revised the format, typeset the equations and offered valuable comments on the content.

INTRODUCTION

The ***Mathematics for Water and Wastewater Operations*** manual has been prepared to assist the participants and instructors achieve the learning objectives for the mathematical topics in the following utility operations training courses:

- Basic Water Treatment Operation (OPS 150)
- Basic Wastewater Treatment Operation (OPS 100)
- Surface Water Treatment (OPS 250)
- Activated Sludge (OPS 200)
- Wastewater Sludge Technology (OPS 210)

These manuals traditionally are included with the materials sent to the participant prior to the course upon confirmation of registration.

OBJECTIVES

An operator of a water or wastewater treatment plant should routinely evaluate the efficiency of the individual process units and of the plant. Basic mathematical concepts are essential for the operator to maintain efficient plant operation and compliance with environmental approvals and regulations.

The objective of this manual is to help the operator to determine process efficiency through the use of mathematical calculations rather than "trial and error" methods. This manual will not dwell on mathematics in general but rather is intended to act as a guide to the operator by providing examples of typical "in-plant" calculations.

Water Treatment Plant Operators should be able to perform the following mathematical calculations :

- utilization of formulae
- area, volume and ratio calculations
- dosage calculations for chemicals used in water treatment
- rate of flow calculations
- detention times
- process loading calculations
- pump / feed rate calculations
- filter loading calculations
- backwash water suspended solids concentrations
- groundwater / well calculations

Wastewater Treatment Plant Operators are required to perform the following in the application of their knowledge to "in-plant" processes.

- utilization of formulae
- area, volume and ratio calculations
- dosage calculations for chemicals used in wastewater treatment
- rate of flow calculations
- detention times
- Activated Sludge calculations including:
  - mixed liquor suspended solids determination (MLSS)
  - volatile suspended solids determination (MLVSS)
  - food/microorganism ratio (F/M Ratio)
  - sludge wasting
  - specific uptake rate (SUR)
  - biochemical oxygen demand (BOD)
  - loading calculations
- Sludge Digestion calculations including:
  - digester retention time
  - % solids reduction
  - specific gas production
  - pumping calculations

INSTRUCTION FOR THE USE OF THIS MANUAL

This manual is specifically designed to be used in conjunction with the manuals for the following courses: Basic Wastewater Treatment, Basic Water Treatment, Surface Water Treatment, Activated Sludge, and Wastewater Sludge Technology. It will accompany the training materials sent out to participants prior to courses.

Prior to attending a course, the contents of this manual and the course manual must be reviewed by the participant. The appropriate section(s) detailed below, is (are) to be completed before coming on the course. A review will be conducted during the course to clarify problem areas.

Section A, **example calculations for water and wastewater operators should be read by all participants before attempting any of the working sections** in this manual.

a. Section B - To be completed by those attending the BASIC WATER TREATMENT OPERATION course.

b. Sections I, J & K - To be read and completed by those attending the SURFACE WATER TREATMENT course.

c. Section C - To be read and completed by those attending the BASIC WASTEWATER TREATMENT OPERATION course.

d. Sections D, E, J & K - To be read and completed by those attending the ACTIVATED SLUDGE PROCESS course.

e. Sections F,G, J & K - To be read and completed by those attending the WASTEWATER SLUDGE TECHNOLOGY course.

Complete each question. Space is provided in the working sections for this purpose. If you run out of space, use a piece of foolscap and insert it between the pages of this manual.

Answers to exercises are included at the end of this manual. These should be used to verify your calculations only after completing the exercises. The answer itself is merely a number that represents a certain value or quantity, and is not important by itself. What is important is the ability of the participant to understand and use the correct concept(s) in solving routine plant problems. The method of arriving at an answer is the most important aspect of problem solving.

PRACTICAL MATH FOR TREATMENT PLANT OPERATORS

In most plants routine laboratory tests are performed to ensure that the plant operates under optimum conditions. The analysis of samples, as determined in the laboratory, will assist the operator in deciding whether any adjustments are necessary to the treatment units to achieve the optimum degree of efficiency. The operator must be able to understand the significance of the laboratory results and be able to apply relevant laboratory and other data to perform specific mathematical calculations.

The following material contains sample problems of typical "in-plant" situations as well as a "step-by-step" description of what the participant might consider when solving these problems. IT IS THE RESPONSIBILITY OF THE OPERATOR TO BECOME FAMILIAR WITH THE MORE FUNDAMENTAL CONCEPTS OF MATHEMATICS!

THE APPROACH

Before you try to solve a mathematical problem, how should you approach it?

Do not write anything until you have read the question thoroughly. Quite often the questions are "word problems", so rather than focus attention on the numbers given, you should first ask yourself some very basic questions about the mathematical problem itself:

(1) What are you asked to find?

(2) What concept is involved (e.g. volume, area)?

(3) Can you draw a diagram or mentally project what is happening?

(4) What are you told about the situation you are asked to solve?

(5) Are there any formulae you have come across that are applicable to the problem?

(6) Is there any information not given to you or is it hidden somewhere in the question, perhaps in another form or with different units that need conversion?

(7) Is there extraneous information not applicable to solving the problem?

Up to this point, you have not used any mathematics. You have examined the situation and depicted in the problem. By understanding the "in-plant" processes involved and using mathematics, you can verify that your observations are correct . Answers from test results will help you understand plant processes.

There are some basic math concepts that, once mastered, will make your calculations seem simple. The equations quite often look very complex but once you realize that all they do is represent words and ideas concerning plant processes, you will find that they aren't difficult. As a result, you should make yourself familiar with the operations and processes involved when dealing with equations. You must be aware of "units"; they tell you in what terms you are talking (e.g. metres, litres per second, etc.) and also you will have to learn how to convert from one unit to another (cm to m, m^3 to litres).

In summary, if you completely understand the processes taking place in your plant and if you make an effort to learn the relatively few basic mathematical concepts involved, math for your "in-plant" calculations will present no difficulties at all.

SECTION A

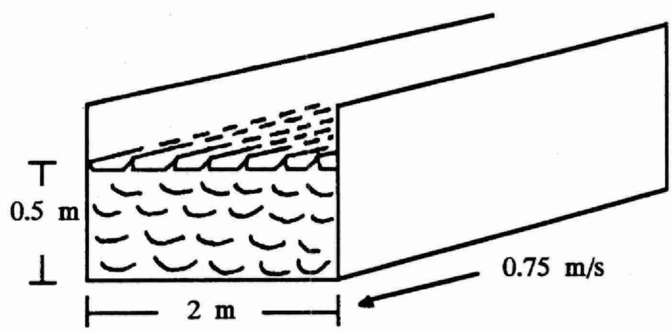
EXAMPLE CALCULATIONS FOR WATER & WASTEWATER OPERATORS

RATE OF FLOW CALCULATIONS

These calculations are important as they provide data that is necessary in determining the cost of treatment and the efficiency of the process control equipment. The accuracy of the flowmeters and pumping capacities can be checked and the measurement of flows, contributed by various sources, such as ground water run-off or industrial wastes, can be estimated with some degree of accuracy. Rates of flow must be determined for proper sizing of clarifiers, aeration tanks, grit chambers, filters , feed rate calculations, etc.

EXAMPLE 1

A channel 2 m wide has a water flowing to a depth of 0.5 m. What is the daily FLOW in the channel if the velocity of the water is 0.75 m/s?



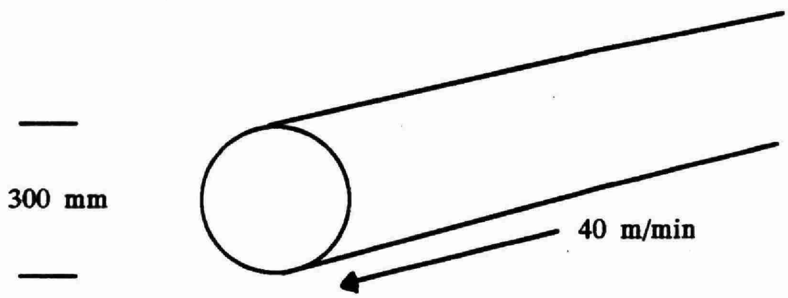
$$RATE\ OF\ FLOW = WIDTH \times DEPTH \times VELOCITY$$
$$= (2\ m) \times (0.5\ m) \times (0.75\ m/s)$$
$$= 0.75\ m^3/s$$

However, we are asked to find the daily flow.

$$Daily\ Flow = rate\ of\ flow \times 60\ s/\text{min} \times 1440\ \text{min}/d$$
$$= (0.75\ m^3/s) \times (60\ s/\text{min}) \times (1440\ \text{min}/d)$$
$$= 64800\ m^3/d$$

EXAMPLE 2

What is the daily FLOW in a 300 mm diameter pipe that is flowing 75% full if the velocity is 40 m/min?



(1) Convert applicable data to the same units:

$$\textit{Diameter} = 300\ mm = 0.3\ m$$

$$\textit{Radius} = \frac{\textit{Diameter}}{2} = 0.15\ m$$

(2) Apply data to formula:

$$\textit{Rate of Flow} = \textit{Cross Sectional Area} \times \textit{Velocity}$$

$$= \Pi\ r^2 \times V$$

However the pipe flows at 75% full.

$$\textit{Rate of Flow} = 0.75\ (\ \Pi\ r^2 \times V\ )$$

$$= 0.75 \times (\ 3.14\ ) \times (\ 0.15\ m\ ) \times (\ 0.15\ m\ ) \times \left(\frac{40\ m}{\text{min}} \right)$$

$$= 2.1\ \frac{m^3}{\text{min}}$$

We need to convert 2.1 m^3 /min to a standard expression of flow rate. Either L/s or m^3/d are correct, and we are asked to put the answer in terms of daily flow (m^3/d).

$$\begin{aligned} \textit{Daily flow} &= \textit{Volume of flow} \times 1440 \text{ min}/d \\ &= (2.1 \ m^3/d) \times (1440 \text{ min}/d) \\ &= 3024 \ m^3/d \end{aligned}$$

PERCENT

EXAMPLE 1

A lime solution having a mass of 80 kg contains 85% water and the remainder is lime. What is the mass of the lime?

SOLUTION

The total mass of the solution is 80 kg which represents 100%.If the water represents 85%, then the lime represents:

$$(\textit{Total Mass}) - (\textit{Mass of Water}) = (\textit{Mass of Lime})$$

$$100\% - 85\% = 15\%$$

$$\begin{aligned} \textit{Mass of Lime} &= 15\% \times 80\ kg \\ &= .15 \times 80\ kg \\ &= 12\ kg \end{aligned}$$

EXAMPLE 2

An alum solution having a mass of 200 kg contains 176 kg of water and the rest is alum. a) What percentage of the mixture is water? b) What percentage of the mixture is alum?

SOLUTION

a) In the above question we are told the total mass of the mixture is 200 kg or 100%. The mass of the water is 176 kg.

To find the percentage of water:

$$\begin{aligned} \%\ \textit{of Water} &= \frac{176\ kg}{200\ kg} \times 100\% \\ &= 88\% \end{aligned}$$

b) Obviously if 88% of the mixture is water then:

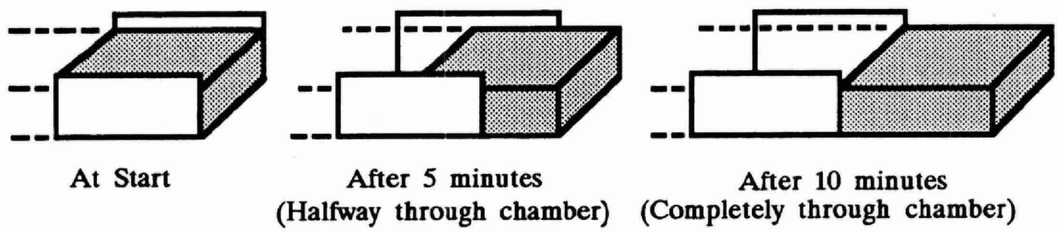
$$\textit{Total Mass} - \textit{Mass of Water} = \textit{Mass of Alum}$$

$$100\% - 88\% = 12\%$$

DETENTION TIME

The concept of detention time is used in conjunction with many treatment plant processes. "**DETENTION TIME**" refers to the length of time a drop of water or a suspended particle remains in a tank or chamber.

Detention time may also be thought of as the number of minutes or hours required for each tank to fill and overflow. The mental image might be one of the flow from the time water enters the tank until it leaves the tank completely ("plug flow"), as shown in the following figure.



TEN MINUTES DETENTION TIME

EXAMPLE

A sedimentation tank has a capacity of 132 m^3. If the hourly flow to the clarifier is 47 m^3/h, what is the detention time?

Since the flow rate is expressed in hours, the detention time calculated is also in hours:

$$\textit{Detention Time} = \frac{\textit{Volume of Tank}}{\textit{Flow rate}}$$

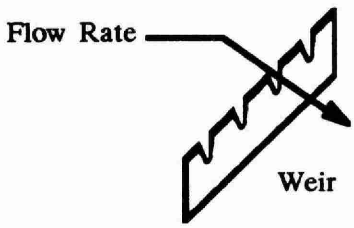
$$= \frac{132\ m^3}{47\ m^3/h}$$

$$= 2.8\ h$$

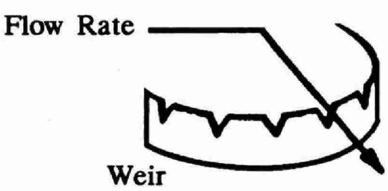
WEIR OVERFLOW RATE

The calculation of **WEIR OVERFLOW RATE** is important in detecting high velocities near the weir, which adversely affect the efficiency of the sedimentation process. When excessively high velocities occur the settling solids are pulled over the weirs and into the effluent troughs.

In calculating the weir overflow rate, you will be concerned with the litres per second flowing over each metre of weir length. The following figures can be associated with weir overflow rate in rectangular and circular sedimentation basins.



WEIR OVERFLOW RATE
Rectangular Clarifier
(Sedimentation Tank)



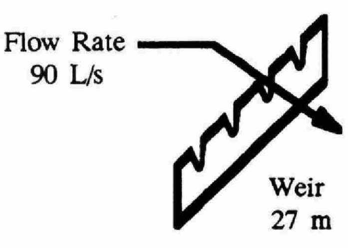
WEIR OVERFLOW RATE
Circular Clarifier

Since weir overflow rate is L/s flow over each m of weir length, the corresponding mathematical equation is:

$$\textit{Weir overflow rate} = \frac{flow\ (\ L/s\ )}{weir\ length\ (\ m\ )}$$

EXAMPLE 1

If a sedimentation tank has a total of 27 m of weir over which the water flows, what is the weir overflow rate when the flow is 90 L/s?



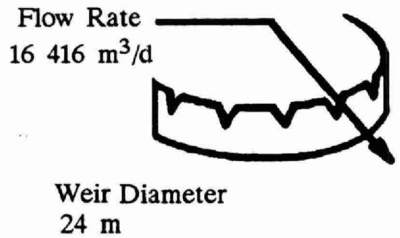
$$Weir\ overflow\ rate = \frac{flow\ (\ L/s\ )}{weir\ length\ (\ m\ )}$$

$$= \frac{90\ L/s}{27\ m}$$

$$= \frac{3.3\ L/s}{m}$$

EXAMPLE 2

A circular clarifier receives a flow of 16 416 m^3/d. If the diameter is 24 m, what is the weir overflow rate?



Before you can calculate the weir overflow rate, you must know the total length of the weir. The relationship of the diameter and circumference of a circle is the key to determining this problem.

Circumference = 3.14 x Diameter

In this problem, the diameter is 24 m. Therefore, the length of weir (circumference) is:

$$Circumference = (\ \pi\ )\ (\ Diameter\ )$$

$$= (\ 3.14\ )\ (\ 24\ m\ )$$

$$= 75.4\ m$$

We now must convert 16416 m^3/d to L/s by the following:

$$16416\ \frac{m^3}{d} \times \frac{1000\ L}{m^3} \times \frac{d}{86{,}400\ sec} = 190\ L/s$$

Now solve for the weir overflow rate:

$$\begin{aligned} Weir\ overflow\ rate &= \frac{flow\ (\ L/s\ )}{weir\ length\ (\ m\ )} \\ &= \frac{190\ L/s}{75.4\ m} \\ &= \frac{2.5\ L/s}{m} \end{aligned}$$

PUMPING RATES

The rate of flow produced by a pump is expressed as the volume of water pumped during a given period of time. The mathematical equation used in pumping rate problems can usually be determined from the verbal statement of the problem.

VERBAL: What is the pumping rate in m^3 per day?

MATH: pumping rate = x m^3/d

VERBAL: What is the pumping rate in litres per second?

MATH: pumping rate = x L/s

The volume pumped during a period can be determined either by a flowmeter or by measuring the volume being pumped into or out of a tank.

Most pumping rate problems will ask you to give an answer in one form (L/s) and will give you the information in another form (m^3/d). At first the conversion between these two expressions looks difficult, but once you become familiar with their relationship to each other, converting is simple. Here is the conversion:

$$\frac{m^3}{day} \times \frac{1000\ L}{1\ m^3} \times \frac{1\ day}{86{,}400\ sec.} = \frac{1000\ L}{86{,}400\ s}$$

EXAMPLE

An empty rectangular tank 8 m long and 6 m wide can hold water to a depth of 2 m. If this tank is filled by a pump in 55 min. **(a)** What is the pumping rate in litres per second?
(b) What is the pumping rate in cubic meters per day?

In this example, the entire tank was filled during the 55 min pumping test. Therefore the total volume pumped is equal to the capacity of the tank in m^3.

$$\begin{aligned} \textit{Volume of Tank} &= \textit{Area of Rectangle} \times \textit{Depth} \\ &= (8\ m)(6\ m) \times (2\ m) \\ &= 96\ m^3 \end{aligned}$$

(a) To find L/s we convert 96 m^3 to litres and 55 min to seconds.

$$96\ m^3 \times \frac{1000\ L}{m^3} = 96000\ L$$

$$55\ \text{min} \times \frac{60\ s}{\text{min}} = 3300\ s$$

Then we divide :

$$\frac{96000\ L}{3300\ s} = 29.1\ L/s$$

(b) To find the m^3/d, we know that 96 m^3 was pumped in 55 minutes.

$$\frac{96\ m^3}{55\ \text{min}} \times \frac{1440\ \text{min}}{d} = 2513\ \frac{m^3}{d}$$

DENSITY

For scientific and technical purposes, the DENSITY of a body of material is precisely defined as the mass PER UNIT OF VOLUME. The density of dry materials, such as sand, activated carbon, lime and liquids such as water, liquid alum or liquid chlorine can be expressed as g/cm^3. The density of gases, such as air, chlorine, methane or carbon dioxide is normally expressed in g/L.

The density of a substance CHANGES SLIGHTLY AS THE TEMPERATURE OF THE SUBSTANCE CHANGES. This happens because substances usually increase in volume as they become warmer, as illustrated in Figure 1. Because of the expansion with warming, the mass is spread over a larger volume, so the density is less when a substance is warm than when it is cold.

Similarly, a change in pressure will change the volume occupied by a substance. As a result, DENSITY VARIES WITH PRESSURE, increasing as pressure increases and decreasing as pressure decreases (Figure 2).

The effects of pressure and temperature on solids and liquids, are very small and are usually ignored. However, temperature and pressure have a significant effect on the density of gases and whenever the density of a gas is given, then the temperature and pressure at that density are usually given as well.

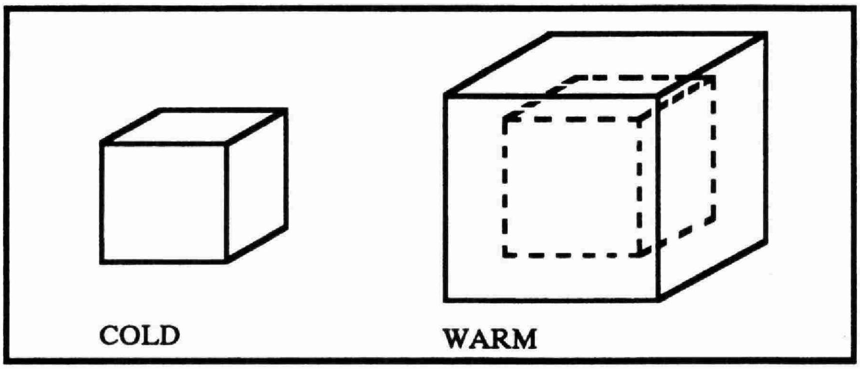


Figure 1. Density Changes as Temperature Changes

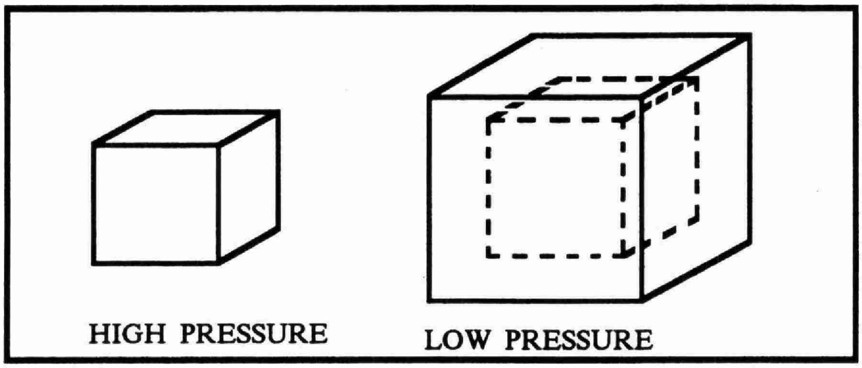


Figure 2. Density Changes as Pressure Changes

SPECIFIC GRAVITY (Relative Density)

Although there may be many numbers that express the density of the same substance (depending on the unit used) there is only one relative density associated with each substance (for one particular temperature and pressure). The relative density of a substance is compared against a "Standard" density.

SPECIFIC GRAVITY OF SOLIDS & LIQUIDS

The standard density used for solids and liquids is that of water, which is one g/cm^3 at 4 degrees C and a pressure of 101.3 kN/m^2 or kilopascals (kPa), the pressure of the atmosphere at sea level. Therefore, the specific gravity of a solid or liquid is the density of that solid or liquid COMPARED TO THE DENSITY OF WATER. It is the ratio of the density of that substance to the density of water. Let's look at an example. The density of SAE 30 motor oil is:

$$Specific\ Gravity = \frac{oil}{water} = \frac{0.9\ g/cm^3}{1.0\ g/cm^3} = 0.90$$

In other words, specific gravity in this example tells you that oil is only 9/10 as dense as water. Because a cm^3 of oil has a mass less than a cm^3 of water, oil floats on the surface of water.

Specific Gravity of Gases

The specific gravity of a gas is usually determined by comparing the density of the gas with the density of air, which is 1.2 g/L at a temperature of 20 degrees C and a pressure of 101.3. (kN/m) or kilopascals (kPa) the pressure of the atmosphere at sea level. For example, the density of chlorine gas is 2.99 g/L. Its specific gravity would be calculated as follows:

$$Specific\ Gravity = \frac{Cl_2}{air} = \frac{2.99\ g/L}{1.2\ g/L} = 2.49$$

This tells you that chlorine gas is approximately 2.5 times as dense as air. Therefore, when chlorine gas is introduced into a room it will concentrate at the bottom of the room. This is important to know since chlorine is a toxic gas.

DOSAGE CALCULATIONS

It is most necessary for a plant operator to know how to calculate the dosages of the various chemicals used in water and wastewater treatment. It is important to be accurate when calculating dosages as too little or too much chemical may be ineffective and too much chemical is a waste of money. In process control the exact dose of chemical must be determined through calculation for the purposes of efficient operation and economy.

EXAMPLE 1

The chlorine dosage of an effluent is 15 mg/L. How many kilograms of chlorine will be required to dose a flow of 8 500 m^3/d? In this question, it will be necessary to utilize your knowledge of the metric system.

1 mg/L = 1 kg/ 1 000 m^3

For every 1 000 m^3 of water of flow, we will need to use 15 kg of chlorine.

$$\frac{15\ kg\ Cl_2}{1000\ m^3} \times 8500\ m^3/d = 127.5\ kg\ Cl_2\ /d$$

Above we expressed 15 mg/L as 15 kg Cl_2 / 1 000 m^3 and multiplied it by the flow to obtain the answer expressed as 127.5 kg Cl_2/d.

EXAMPLE 2

A chlorinator is set to feed a 94.8 kg/d of chlorine. If the average daily flow through the plant is 7 900 m^3/d, what is the DAILY AVERAGE CHLORINE DOSAGE IN mg/L?

We know that: $$1\ mg/L = \frac{1\ kg}{1000\ m^3}$$

We are told we use 94.8 kg chlorine for every 7900 m^3 water.

$$\frac{94.8\ kg\ Cl_2\ /d}{7.9 \times 1000\ m^3/d} = \frac{12\ kg\ Cl_2}{1000\ m^3} = 12\ mg/L$$

Above we divide the mass of chlorine used per day by the flow expressed in 1 000 m^3 per day and found we used 12 kg Cl_2 for every 1 000 m^3 of flow or 12 mg/L.

HYPOCHLORINATION CALCULATIONS

Definition - Hypochlorination is the application of hypochlorite (a compound of chlorine and another chemical), usually in the form of solution, for disinfection purposes.

EXAMPLE 1

The secondary effluent at a treatment plant requires a chlorine dosage of 98 kg/d for disinfection purposes. If we are using a solution of hypochlorite containing 60% available chlorine, how many kg/d hypochlorite will be required?

SOLUTION

We are told in the problem that 60% of the hypochlorite is available chlorine which is the portion of the solution capable of disinfecting. Solving the equation we have:

$$kg/d\ hypochlorite = \frac{98\ kg/d\ of\ Chlorine\ needed}{0.6\ available\ Chlorine\ in\ sol'n} = 163.3\ kg/d\ hypochlorite\ solution$$

EXAMPLE 2

A hypochlorite solution contains 5% available chlorine. If 4 kg of available chlorine are needed to disinfect a watermain, how much 5% solution would be required?

We are told 4 kg of chlorine will do the job of disinfection. By a 5% solution we mean that 5% by mass of the solution is to be made up of chlorine. Thus 100 kg of 5% hypochlorite solution will contain 5 kg chlorine.

$$\frac{5\ kg\ chlorine}{100\ kg\ sol'n} = \frac{4\ kg\ chlorine\ required}{?\ kg\ sol'n} = 80\ kg\ sol'n$$

CHEMICAL FEEDING

Solution Preparation - Jar Tests

Jar tests are used to determine correct chemical dosages for such chemicals as alum, ferric chloride and polymers. These are chemicals utilized in water treatment facilities for coagulation and flocculation of colloidal particles and are used in wastewater treatment facilities for chemical precipitation of phosphorous. The jar test simulates, on a small scale, the activities going on in various sections of the full scale treatment process. Varying amounts of the chemicals are compared against each other to find out which chemical and dosage best accomplishes the desired results.

Stock solutions of coagulants, coagulant aids and other chemicals, should be prepared at concentrations such that quantities suitable for use in the jar tests can be measured accurately and conveniently. If one is dealing with dry chemicals the preparation of these stock solutions is straight forward. For example to prepare a 1 gm/L stock solution using dry chemicals, 1 gram of the chemical is made up to 1 000 mL with distilled water. However, with concentrated liquid solutions a dilution step is required. Any dilution step must take into account the specific gravity of the solution being diluted. For example, if one has a 48.5% alum solution with a specific gravity of 1.35 and wishes to make up a 1 gm/L stock solution the following procedure should be followed:

1 mL 48.5% w/w liquid alum has a mass of 1.35 g

1 mL contains

$$1.35\ g \times \frac{48.5}{100} = 0.65\ g\ dry\ alum$$

Then

$$\frac{1\ mL}{0.65\ g} = \frac{x\ mL}{1\ g}$$

$$x = 1.54\ mL$$

Therefore 1.54 mL of a 48.5% w/w liquid alum solution contains 1 gram of dry alum.

Using a 1 Litre volumetric flask:

(1) A 1 g/L (0.1% w/v) stock solution may be prepared by adding 1.54 mL liquid alum to the flask and topping up with distilled water to the one litre meniscus (i.e. the total volume does not exceed 1 litre). This concentration should only be used in jar tests requiring less than 10 mg/L dosage.

(2) A 10 g/L (1.0% w/v) stock solution may be prepared by adding 15.4 mL liquid alum to the flask and topping up with distilled water to the one litre meniscus . A 1% w/v (10 g/L) solution should be made up for jar tests requiring more than 10 mg/L dosage. This reduces the amount of chemical added to the raw water and therefore increases the accuracy of the jar test.

Jar tests are carried out to determine the chemical dosage and point of application best suited to the characteristics of the water or sewage to be treated. This information is then applied to the full scale treatment. If feeding dry chemicals, the feeder will be calibrated, most likely, in grams per minute or, if liquid chemicals are being utilized, in millilitres per minute. Following is a detailed approach to establishing feed rates for chemicals:

Example

Given a daily flow rate of 16 000 m^3/d and Fe^{3+} dosage of 13 mg/L, what is the ferric chloride ($FeCl_3$) feed rate in mL/min?

Ferric Chloride (Specific Gravity) 1.39 kg/L
Fe^{3+} is 13.7% by mass in the solution

Step 1: Determine kg/d of Fe^{+3} required.

$$1.\ Fe^{3+}\ dosage\ of\ 13\ mg/L = \frac{13\ kg}{1000\ m^3}$$

2. *Feed Rate* $= Dosage \times Flow$

$$= \frac{13\ kg}{1000\ m^3} \times \frac{16000\ m^3}{d}$$

$$= 208\ kg/d\ Fe^{3+}$$

Step 2: Determine kg/d of solution. (Remember: Fe^{3+} is 13.7% by mass of solution.)

$$Amount\ of\ solution\ required = \frac{208\ kg/d}{0.137} = 1518.2\ kg/d$$

Step 3: We are asked to give the feed rate in mL/min.

1. Convert kg/d to L/d. Since 1 L has a specific gravity of 1.39 kg/L:

$$\frac{1518.2\ kg}{d} \div \frac{1.39\ kg}{L} = \frac{1092.2\ L}{d}$$

2. Convert L/d to mL/min. Since 1 L is equivalent to 1 000 mL.

$$\frac{1092.2\ L/d \times 1000\ mL/L}{1440\ \text{min}/d} = 758.8\ mL/\text{min}$$

SECTION B

MATH FOR BASIC WATER TREATMENT OPERATIONS

1. Calculate the surface area of a rectangular settling tank 18 m long and 4 m wide.

2. Calculate the surface area of a circular sand filter that has a diameter of 15 m.

3. Calculate the volume of a raw water intake crib that is 8 m long, 3 m wide and 6 m deep.

4. What is the volume of a cylindrical storage tank that is 7 m in diameter and 15 m high?

5. What is the volume of water contained in 84 m of a 10 cm diameter pipe?

   a) in m^3

   b) in L

6. If a pump delivers 1 44 m^3 in 20 minutes, what is the pumping rate expressed in:

   a) L/s?

   b) m^3/d?

7. How many m^3 of water will a 5 L/s pump deliver in 5 minutes?

8. A 12 m^3 storage tank supplies alum for coagulation at a rate of 330 mL/min. How often will the tank need refilling?

9. The prechlorination chamber at a water treatment plant has a volume of 225 m^3. If the flow rate out of the tank is 11 L/s, what is the average detention time in hours?

10. How many kg of chlorine are required each day to treat 18 000 m^3 with chlorine at 5.0 mg/L?

11. A gas chlorinator treats 2 700 m^3 with 2 kg of chlorine each day. Calculate the dosage rate. The residual is measured at 0.27 mg/L. What is the chlorine demand?

a) in mg/L

b) in kg/d

12. In the chart below you are required to determine the mass of chemical in kg that will be required to feed at the rate indicated along the top of the chart in relationship to the volume of water flowing in which is indicated down the side.

Dosage rate / Volume of water	1.0 mg/l	2.0 mg/l	4.0 mg/l	10 mg/l	0.5 mg/l
1,000 m^3	1.0				
4,000 m^3					
20,000 m^3					
500 m^3					
200 L					

13. In the chart below you are required to determine the dosage in mg/L that coincides with the volume indicated on the vertical scale and the mass of alum indicated on the horizontal scale.

Mass / Volume of water	1.0 kg	2.0 kg	5.0 kg	20 kg	0.4 kg
1,000 m^3					
5,000 m^3					
10,000 m^3					
200 m^3					

14. A liquid solution with a total mass of 97 kg contains 84 kg of water and the remainder is alum.

a) Calculate the percent that is water.

b) Calculate the percent that is alum.

15. A mixture of water and powdered carbon is to be 85% water. If the total volume of solution required is
3.6 m^3, what is the mass of the powdered carbon?

16. A hypochlorite solution contains 12% available chlorine. If 3 kg of available chlorine are needed to disinfect a main:

a) How many kg of solution are required?

b) How many litres of solution are required?

WATER TREATMENT MATH

EXTRA PRACTICE CALCULATIONS

1. Calculate the volume of water contained in 30 m of pipe that is 412 mm in diameter.

2. A rectangular storage tank for an alum solution that is 7 m long, 5 m wide and 3 m deep after filling takes 30 days to empty. What is the rate at which the alum solution is being used up ? (Express the answer in m^3/d).

3. A mixture is composed of three substances: water, powdered carbon and alum and the total mass is 900 kg. Calculate the mass of each substance if it is known that 70% is water and 25% is carbon.

4. A water treatment plant has a flow of 2 700 m^3/d. If the average detention time in the chlorine contact chamber is to be 12 minutes, what should the volume of the chamber be?

5. A 0.0005% concentration of copper sulphate is used for controlling algae in a reservoir. The volume of the reservoir is 172 800 m^3. What is the mass of copper sulphate required?

6. A well produces 1 800 m^3 of water and is chlorinated by using 26 kg of chlorine each day. Calculate the dosage.

7. An operator chlorinates a well water supply, using a hypochlorinator. The well pump rate is 450 L/s the hypochlorite solution is 20% available chlorine and the dosage is 2.5 mg/L. How many litres of hypochlorite solution are used daily?

SECTION C

MATH FOR WASTEWATER TREATMENT OPERATIONS

1. What is the surface area of a rectangular clarifier 7 m wide and 20 m long?

2. What is the surface area of a circular clarifier 14 m in diameter?

3. What is the volume of a chlorine contact chamber 8 m long, 3 m and 2 m deep?

4. What is the volume of a cylindrical storage tank that is 10 m in diameter and 13 m high?

5. If a pump delivers 1.32 m^3 in 20 minutes, what is the pumping rate in:

a) L/s?

b) m^3/d?

6. A 6 L/s pump operates for 5 min^]
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ch water is pumped?

7. A 12.3 m^3 alum storage tank supplies alum for phosphorous removal treatment at a rate of 342 mL/min. How often will the tank need refilling?

8. Sewage flows through a rectangular channel 1 m wide and 60 cm deep at a rate of 2.6 m/s. What is the flow rate in:

a) m^3/s?

b) L/s?

9. The aeration section of a 900 m^3/d plant has a volume of 225 m^3. What is the average detention time of the aeration section?

10. In the chart below you are required to determine the mass of chemical in kg that will be required to feed at the rate indicated along the top of the chart in relationship to the volume of water flowing in which is indicated down the side.

Dosage rate Volume of water	1.0 mg/l	2.0 mg/l	4.0 mg/l	10 mg/l	0.5 mg/l
1,000 m^3					
4,000 m^3					
20,000 m^3					
500 m^3					
200 L					

11. What mass of chlorine is required daily to dose the effluent of an 10 000 m^3/d plant at 5.0 mg/L?

12. In the chart below you are required to determine the dosage in mg/L that coincides with the volume indicated on the vertical scale and the mass of ferric chloride indicated on the horizontal scale.

Mass of $FeCl_3$ / Volume of water	1.0 kg	2.0 kg	5.0 kg	20 kg	0.4 kg
1,000 m^3					
5,000 m^3					
10,000 m^3					
200 m^3					

13. A gas chlorinator is set to dose an effluent of 2 700 m^3/d with 10 kg of chlorine each day. If the chlorine demand is 3.0 mg/L calculate the chlorine residual in:

a) mg/L

b) kg/d

WASTEWATER TREATMENT MATH

EXTRA PRACTICE CALCULATIONS

1. An aerator tank is 3 m deep, 7 m wide and 17 m long. Calculate its volume?

2. A 2 400 m^3 tank has a detention time of 5 hours. Calculate the flow in:

   a) L/s

   b) m^3/d

3. The venturi meter at a plant records a fairly constant flow of 1 000 m^3/d while at the same time the operator observes that the flow in the channel (0.6 m wide and 0.2 m deep) is about 0.1 m/s. Is the meter recording accurately?

4. If the chlorine dose rate at a 1 400 m^3/d plant is 6.0 mg/L. How much chlorine is consumed daily?

5. Raw sewage entering the primary clarifier has a suspended solids content of 250 mg/L. The concentration is reduced to 150 mg/L in the primary effluent and 15 mg/L in the final effluent. Calculate the solids removal efficiency (in percent) of the:

   a) primary section

   b) the whole plant

SECTION D

EXAMPLE CALCULATIONS FOR ACTIVATED SLUDGE

MIXED LIQUOR SUSPENDED SOLIDS DETERMINATION (MLSS)

MLSS is usually reported in mg/L, and is determined using the formula:

$$MLSS = \frac{(B - A) \times (1000\ mg/g)\ (1000\ mL/L)}{V\ (mL)}$$

Where:

B	=	Dried mass of filter paper and solids (in grams)
A	=	Dried filter paper mass (in grams)
V	=	Volume of sample used in mL (aliquot)

1 000 mg/g converts mass in grams to mass in milligrams and 1 000 mL/L converts volume from mL to litres.

EXAMPLE

Given:

Sample volume of mixed liquor used	=	50 mL
Dried filter paper mass (Tare)	=	0.215 7 g
Dried mass of filter paper + solids (Gross)	=	0.437 6 g

Determine the MLSS in mg/L

SOLUTION

$$MLSS = \frac{(0.4376\ g - 0.215\ g)\ (1000\ mg/g)\ (1000\ mL/L)}{50 mL}$$

$$= \frac{(0.2219\ g)\ (1000\ mg/g)\ (1000\ mL/L)}{50\ mL}$$

$$= 4438\ mg/L$$

F/M RATIO

F/M RATIO (FOOD/MICROORGANISM RATIO) is the relationship between the mass of food (measured by BOD_5 of the aerator influent) and the mass of the microorganisms in the aerator (as measured by the MLVSS).

$$\frac{F}{M} = \frac{BOD_5\ kg}{MLVSS\ kg}$$

When operating an activated sludge process, it must be maintained within the recommended F/M ranges by controlling the aeration MLVSS concentration. Otherwise aeration mixed liquor flocculation will be disrupted or filamentous organisms may develop causing poor sedimentation. To correct an F/M ratio outside of the recommended range, the operator must change the wasting rate to effect a change in MLVSS.

EXAMPLE 1

A conventional activated sludge plant treatment receives a daily flow of 20 250 m^3/d with a primary effluent BOD_5 of 165 mg/L. If 6 750 kg of MLVSS are maintained in the aerator, what is the F/M ratio?

SOLUTION

BEFORE determining the F/M loading ratio, we must calculate the mass of BOD entering the aerator daily. Therefore, we must convert mg/L BOD to kg of BOD daily.

a) $$165\ mg/L = \frac{165\ Kg}{1\ 000\ m^3}$$

$$\frac{165\ kg}{1\ 000\ m^3} \times \frac{20\ 250\ m^3}{d} = 3\ 341.25\ Kg\ BOD\ /\ d$$

b) $$\frac{F}{M} = \frac{kg\ BOD\ daily}{kg\ MLVSS\ in\ aerator}$$

$$= \frac{3341.25\ kg\ BOD/d}{6750\ kg\ MLVSS}$$

$$= 0.495$$

SOLIDS RETENTION TIME (S.R.T.) = SLUDGE AGE = M.C.R.T.

The length of time that biological solids are held within the process is known as the Solids Retention Time (SRT). This length of time is also called the Sludge Age or Mean Cell Retention Time (M.C.R.T.) This factor is stated in days and is calculated as follows:

$$S.R.T.\ (d) = \frac{mass\ of\ aeration\ MLSS\ (kg)}{mass\ of\ wasted\ solids\ (kg/day) + mass\ of\ solids\ in\ effluent\ (kg/day)}$$

Just as with the F/M ratio, S.R.T. can be used to design or maintain an Activated Sludge process for a given treatment efficiency.

For BOD removal, conventional and contact stabilization plants should be designed and operated in an S.R.T. range of 2 to 5 days with the upper limit used for winter operation. If nitrification is also required year-round, then process S.R.T's over 5 days must be utilized. Like F/M, S.R.T. values are adjusted by varying the amount of solids wasted daily.

EXAMPLE

Given:

Suspended Solids Concentration in effluent	=	15 mg/L
Aeration tank volume	=	1 560 m^3
MLSS	=	2 850 mg/L
FLOW	=	11 400 m^3/d
Daily waste volume	=	100 m^3
Waste A.S. Suspended Solids	=	9 300 mg/L

Find the S.R.T.

SOLUTION

A. Mass of Aeration MLSS in aeration tank

$$\begin{aligned} MLSS &= 2850\ mg/L \times 1560\ m^3 \\ &= 4446\ kg \end{aligned}$$

B. mass of wasted solids (kg/d)

$$Wasted\ solids = (9300\ mg/L) \times (100\ m^3/d)$$
$$= 930\ kg/d$$

C. kg of solids lost in effluent (kg/d)

$$Solids\ Lost = (\ 15\ mg/L\ ) \times (\ 1140\ m^3/d\ )$$
$$= 171\ kg/d$$

D. Solids Retention Time

$$S.R.T. = \frac{4346\ kg}{930\ kg/d + 171\ kg/d}$$
$$= 4.04\ days$$

If the operator wished to increase this to 5 days the amount of solids wasted daily would have to be reduced.

SLUDGE WASTING

In order to attain an equilibrium in the food to microorganisms ratio, it will be necessary to "waste" some activated sludge. There are two ways to waste sludge. Continuous wasting which is proportional to the degree of organic loading in the incoming flow, and batch wasting which is used at times of low hydraulic loads. The amount of sludge to be wasted can be determined if the suspended solids in the aeration tank and sludge return are measured. The excess solids to be wasted are determined by comparing the desired solids in the system with the existing solids.

EXAMPLE

Given a return sludge concentration of 9 800 mg/L suspended solids, a MLSS of 5 300 mg/L, and the aeration tank capacity of 1250 m^3, calculate:

a) What volume of sludge must be diverted to waste in order to reduce the MLSS to 4 200 mg/L?

b) What would be the pumping rate (L/s)

i) if wasted continuously over a 24-hour period?

ii) if batch wasted over a 6-hour period?

SOLUTION

Formula:

$$X = \frac{(M1 - M2)(V)}{R}$$

Where

M1 = MLSS (mg/L)
M2 = Required MLSS (mg/L)
V = Volume aeration tank (m^3)
R = suspended solids in sludge return (mg/L)
X = m^3 to waste

a) The solution of the above problem requires only substitution of given values into the formula.

$$X = \frac{(5300\ mg/L - 4200\ mg/L)(1250\ m^3)}{9800}\ mg/L$$

$$= \frac{(1100\ mg/L)(1250\ m^3)}{9800\ mg/L}$$

$$= 140.3\ m^3$$

b) i) Amount of sludge to be wasted = 140.3 m^3
ii) Time period of wasting = 24 h

i) **Pumping Rate**

$$Pumping\ Rate = \frac{140.3\ m^3}{86400\ sec./d}$$

$$= \frac{140.3\ m^3}{d} \times \frac{1000\ L}{m^3} \times \frac{1\ day}{86400\ sec.}$$

$$= 1.62\ L/sec\ over\ 24\ hours\ continuous\ wasting$$

ii) If batch wasted over six hours:

$$Pumping\ Rate = 1.62\ L/s \times \frac{24}{6}$$

$$= 1.62\ L/sec \times 4$$

$$= 6.495\ L/sec$$

CLARIFIER UPFLOW RATE

The amount of wastewater flowing into a clarifier relative to the surface area of the clarifier is known to affect the settleable solids and BOD removal efficiency during sedimentation.

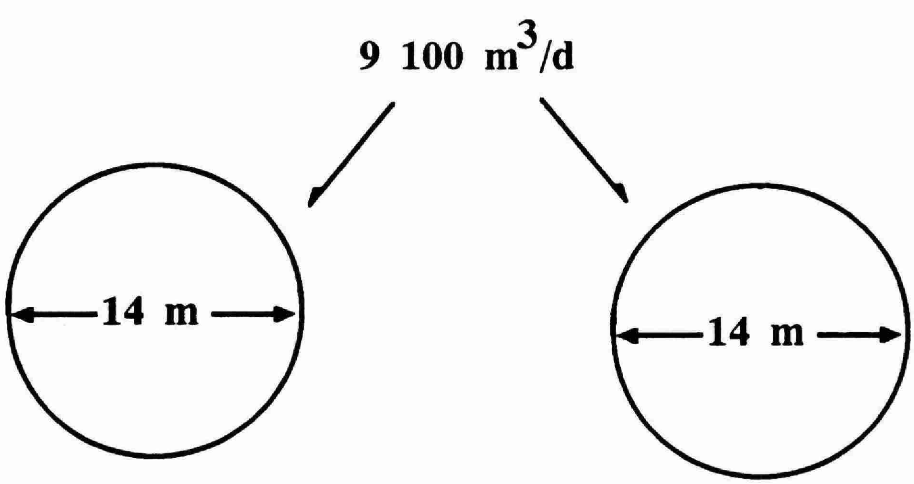
A means of determining this "surface loading rate" is to compare the volume of flow of wastewater entering the clarifier to the surface area of the clarifier. The units of measurement are therefore volume of wastewater daily per square metre of clarifier surface area or:

$$\textit{Surface Loading Rate} = \frac{\textit{average daily flow } (m^3 /d)}{\textit{surface area of clarifier } (m^2)}$$

EXAMPLE

The flow to a treatment plant is 9 100 m^3/d. If there are two final clarifiers, each with a diameter of 14 m calculate the clarifier upflow rate.

SOLUTION



Final Clarifiers

Referring to the above formula, note the information required. Given the daily flow as 9 100 m^3/d, it is necessary to calculate the surface area of the final clarifiers using the formula for the area of a circle

$$A = \pi R^2 \quad or \quad \frac{\pi D^2}{4}$$

Given a diameter of 14 m, the surface area of one final clarifier is:

$$Surface\ Area = \frac{(\ 3.14\ )\ (\ 14\ m)^2}{4} = 153.9\ m^2$$

However, there are two final clarifiers; therefore total clarifier surface area is:

$$Total\ Clarifier\ Area = 2 \times 153.9\ m^2 = 307.8\ m^2$$

$$Upflow\ Rate = \frac{9100\ m^3}{307.8\ m^2}$$

$$= 29.6\ m^3\ /m^2\ /d$$

SLUDGE VOLUME INDEX (SVI)

The Sludge Volume Index (S.V.I.) is defined as the volume, in millilitres, that is occupied by 1 gram of activated sludge after a 30 minute settling test. Normal activated sludge generally has an SVI value in the range of 70-125.

EXAMPLE

If the mixed liquor settled to 285 mL or 28.5% after the 30 minute settling test and the concentration of the mixed liquor suspended solids (MLSS) is 3 250 mg/L what is the SVI?

SOLUTION

$$*SVI = \frac{30 \text{ min. } settling\ test\ results\ (\ mL/L\ ) \times 1000\ (\ mg/g\ )}{MLSS\ (\ mg/L\ )}$$

$$= \frac{285\ (\ mL/L\ ) \times 1000\ (\ mg/g\ )}{3250\ (\ mg/L)}$$

$$= 87.7$$

$$*\ Alternate\ formula\ SVI = \frac{30 \text{ min } settling\ test\ (\ mL\ )}{MLSS\ in\ grams}$$

RESPIRATION RATES

The respiration rate, in the context of the activated sludge process is the rate at which the microorganisms within the aeration tanks use up oxygen. Another phrase for this process is Oxygen Uptake Rate. Respiration rates or uptake rates vary according to the solids concentration in the aeration tank. As a result, the uptake rate is frequently expressed as the "Specific Uptake Rate" (SUR) and this means the amount of oxygen utilized in one hour by one gram of mixed liquor volatile suspended solids.

EXAMPLE

Oxygen consumption of a mixed liquor was measured and recorded over a period of time. From the information provided below, prepare a graph and:

a) calculate the oxygen uptake rate

b) given a volatile suspended solids value of 2 400 mg/L calculate the specific uptake rate.

Time (min)	DO (mg/L)
0	7.8
1	7.7
2	7.3
3	6.8
4	6.4
5	6.0
6	5.4
7	4.8
8	4.3
9	3.7
10	3.0

a) It can be seen from the data that the DO value at time zero is 7.8 mg/L and the DO value at time 10 minutes is 3.0 mg/L. By subtracting the lower DO value from the higher and dividing by the time interval, the uptake rate can be determined as follows:

$$\frac{7.8\ mg/L\ -\ 3.0\ mg/L}{10\ \text{min}} = 0.48\ mg\ O_2\ /L\ .\ \text{min}$$

But the oxygen uptake rate is expressed in the units mg O_2 /L .h.

$$Uptake\ Rate = 0.48\ mg\ O_2\ /\ L\ .\ \text{min} \times 60\ \text{min}/h$$

$$= 28.8\ mg\ O_2\ /\ L\ .\ h$$

b) Specific Uptake Rate (SUR) mg O_2 /h . g MLVSS

$$SUR = \frac{Uptake\ Rate}{MLVSS\ (\ g/L\ )}$$

$$= \frac{28.8\ mg\ O_2\ /\ L\ .\ h}{2.4\ g/L}$$

$$= 12\ mg\ O_2\ /\ h\ .\ g\ MLVSS$$

ORGANIC LOADING (BOD Volume Load)

Organic loading of a trickling filter refers to the daily mass of BOD entering the trickling filter volume. This concept is expressed as:

$$Organic\ Loading = \frac{kg\ BOD/d}{1000\ m^3}$$

EXAMPLE 1

A standard rate trickling filter has a diameter of 36 m and a media depth of 2 m. The flow into the filter is 37.6 L/s with a BOD concentration of 85 mg/L. What is the BOD loading per 1 000 m^3 ?

SOLUTION

First we must determine the daily flow.

$$Pumping\ Rate = 37.6\ L/s$$

$$Daily\ Flow = \frac{(\ 37.6\ L/s\ )\ (\ 86400\ s/d\ )}{1000\ L/m^3} = 3.25 \times 1000\ m^3\ /d$$

Next we calculate kg BOD/day.

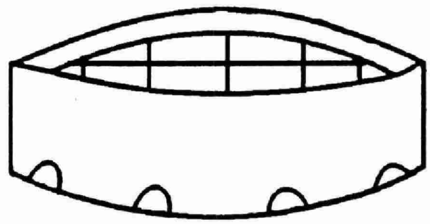
$$BOD = 85\ mg/L \times (\ 3.25 \times 1000\ m^3\ /d\ )$$

$$= \frac{85\ kg}{1000\ m^3} \times \frac{3.25 \times 1000\ m^3}{d}$$

$$= 276.25\ kg\ /d$$

Because organic loading is a mass to volume relationship we must determine the volume of the trickling filter.

Diameter = 36 m
Height = 2 m



$$Volume\ of\ cylinder = \Pi r^2 \times h$$

$$= (\ 3.14\ )\ (\ 18\ m\ )^2\ (\ 2\ m\ )$$

$$= 2.035 \times 1000\ m^3$$

Now we can utilize the relationship

$$Organic\ Loading = \frac{kg\ BOD/d}{1000\ m^3}$$

$$= \frac{276.25\ kg\ BOD/d}{2.035 \times 1000\ m^3}$$

$$= \frac{135.75\ kg\ BOD/d}{1000\ m^3}$$

ORGANIC LOADING

EXAMPLE 2

An aeration tank has the following dimensions: 7 m x 17 m x 5 m. The flow to the aeration tank is 5 900 m^3/d with a BOD concentration of 70 mg/L. Calculate the BOD loading per 1 000 m^3.

SOLUTION

a) Calculate kg BOD/d

$$BOD = 70\ mg/L \times (\ 5.9 \times 1000\ m^3\ /d\ )$$

$$= \frac{70\ kg}{1000\ m^3} \times \frac{5.9 \times 1000\ m^3}{d}$$

$$= 413\ kg\ /d$$

b) Next determine volume of aeration tank.

$$V = L \times W \times H$$

$$= (\ 7\ m\ )\ (\ 17\ m\ )\ (\ 5\ m\ )$$

$$= 595\ m^3$$

c) The final answer is:

$$Organic\ Loading = \frac{kg\ BOD/d}{1000\ m^3}$$

$$= \frac{413\ kg\ BOD/d}{0.595 \times 1000\ m^3}$$

$$= \frac{694.1\ kg\ BOD/d}{1000\ m^3}$$

SECTION E

WORKING SECTION FOR ACTIVATED SLUDGE PROCESS

1. A 50 mL aliquot of mixed liquor is filtered for a suspended solids analysis. The mass of the paper is 0.174 g. After filtering and drying, the paper has a mass of 0.324 g. What is the MLSS concentration?

2. Given a raw sewage flow of 4 500 m^3/d and a BOD in the raw sewage of 150 mg/L calculate the kg of BOD per day entering the aeration section assuming a 20% reduction in BOD across the primary clarifiers.

3. Given that a plant has a daily flow of 4 500 m^3 and an average primary effluent BOD_5 of 150 mg/L, mixed liquor volatile suspended solids (MLVSS) of 1 500 mg/L and an area tank volume of 900 m^3. Calculate the F/M ratio.

4. If the uptake rate is 20 mg O_2 / L.h and the MLVSS is 4 000 mg/L, what is the specific uptake rate?

5. A 460 m^3 aeration tank contains 4 000 mg/L MLSS. The return sludge concentration is 12 000 mg/L. What volume of sludge should be wasted in order to reduce the MLSS to 3 000 mg/L?

6. Calculate the MLSS and SVI using the following information:

a)	Mass of paper	=	0.4004 g
b)	Mass of paper + solids	=	0.5186 g
c)	Sample volume	=	50 mL
d)	30 min settling test	=	21%

7. A 250 mL sample of final effluent is filtered for a suspended solids analysis. The mass of the paper is 0.1560 g. After filtering and drying, the mass of the paper is 0.157 2 g. Express the suspended solids as a concentration in mg/L.

8. An aeration tank has a capacity of 2 270 m^3. If the MLSS is 3 000 mg/L, what is the mass of the solids expressed in kg?

9. The MLSS concentration in a 910 m^3 aeration tank is 4 000 mg/L. This activated sludge contains 75% volatile suspended solids. Express the MLVSS in kg.

10. A flow of 7 730 m^3/d is entering a conventional activated sludge treatment plant. The BOD concentration in the raw sewage is 265 mg/L. If the primary treatment stage of the process removes 23% of the BOD and the F/M ratio in the aerator is 0.5, how many kg of MLVSS should be maintained in the aerator?

11. <u>**Given**</u>

An aeration tank is 27 m long, 20 m wide and water depth is 3 m

MLSS	=	2 550 mg/L
Flow	=	11 370 m^3/d
Daily Waste Volume	=	100 m^3
Waste as Suspended Solids	=	9 000 mg/L
Suspended Solids concentration in effluent	=	15 mg/L

Calculate the SRT.

SECTION F

EXAMPLE CALCULATIONS FOR ANAEROBIC DIGESTION PROCESS

Volatile Acid/Alkalinity Ratio

The volatile acid/alkalinity ratio is the key to successful digester operation. As long as the volatile acids remain low and the alkalinity stays high, anaerobic sludge digestion will occur in a digester. When the ratio starts to increase, corrective action must be taken immediately. This is the first warning that trouble is starting in a digester. If corrective action is not taken immediately or is not effective, eventually the CO_2 content of the digester gas will increase, the pH of the sludge in the digester will drop, and the digester will become sour.

$$\textit{Volatile Acid / Alkalinity Ratio} = \frac{\textit{Volatile Acids mg/L}}{\textit{Total Alkalinity mg/L}}$$

Example

A recirculated sludge from a primary digester has a volatile acids content of 300 mg/L and a total alkalinity of 2 000 mg/L. What is the volatile acid/alkalinity ratio?

Solution

Using the formula above:

$$\textit{Volatile Acid / Alkalinity Ratio} = \frac{300\ mg/L}{2000\ mg/L} = 0.15$$

Solids Calculations

Samples are collected of the raw sludge, recirculated sludge, and supernatant. Each sample is tested for total solids and volatile solids. The information from these tests is used to determine the mass of solids handled through the system, the digester loading rates, and the percent of reduction of the organic matter destroyed by the digester. All of these tests are necessary for the maintenance of efficient digester operation. The volumes of sludge are needed to determine the mass of solids handled through the system.

A. Raw Sludge

If the 12.75 m^3 of raw sludge pumped by the piston pump contains 6.5% total solids and has a volatile content of 68%:

1. What is the mass of the solids contained in the raw sludge?

2. What is the mass of the volatile solids?

Example

Sludge Pumped	=	12.75 m^3
Total Solids	=	6.5%
Volatile Solids	=	68%

1. $$\textit{Mass of total solids (kg)} = \textit{Volume of raw sludge} \times \%\ \textit{Solids as decimal} \times \frac{1000\ kg}{m^3}$$

$$= \frac{(\ 12.75\ m^3\ )\ (\ 0.065\ )\ (\ 1000\ kg)}{m^3}$$

$$= 828.75\ \textit{kg during pumping period}$$

2. $$\textit{Volatile solids (kg)} = \%\ \textit{Volume as decimal} \times \textit{Total Solids}$$

$$= (\ 0.68\ ) \times (\ 828.75\ kg\ )$$

$$= 563.55\ \textit{kg of Volatile Solids during pumping period}$$

B. Recirculated Sludge

Laboratory tests indicate that the total solids in a recirculated digested sludge sample was 4.5% and contained 54.2% volatile solids content. This indicates that the process is reducing the volatile solids content of the sludge, but the 4.5% total solids content is lower than that of the raw sludge being pumped to the digester. The reduction is a result of the conversion of a substantial portion of the volatile solids in the raw sludge to methane, carbon dioxide, and water. Therefore, the reduction in total solids comes from some of the total solids being converted to gas and some of the total solids being washed out with the supernatant.

The reduction of volatile solids that has occurred in the primary digester is arrived at mathematically by the following formula:

$$P = \frac{R - D}{R - (R \, . \, D)} \times 100\% \quad OR \quad \frac{In - Out}{In - (In \times Out)} \times 100\%$$

P	=	Percent Reduction of Volatile Solids
R	=	Percent Volatile Solids in Raw Sludge (In)
D	=	Percent Volatile Solids in Digester Sludge (Out)

Example

In	=	68% Volatile Matter in Raw Sludge
Out	=	54.2% Volatile Matter in Digester Sludge

$$P = \frac{R - D}{R - (R \, . \, D)} \times 100\%$$

$$= \frac{0.68 - 0.54}{0.68 - (0.68 \times 0.54)} \times 100\%$$

$$= \frac{0.14}{0.31} \times 100\%$$

$$= 0.45 \times 100\%$$

$$= 45\%$$

C. Secondary Digested Sludge

Laboratory results indicate that a digested sludge total solids sample was 9.6% and 42.8% volatile solids content. The raw sludge volatile solids content was 68%. The overall percent reduction, P, could then be arrived at by using the formula:

$$P = \frac{R - D}{R - (R \cdot D)} \times 100\%$$

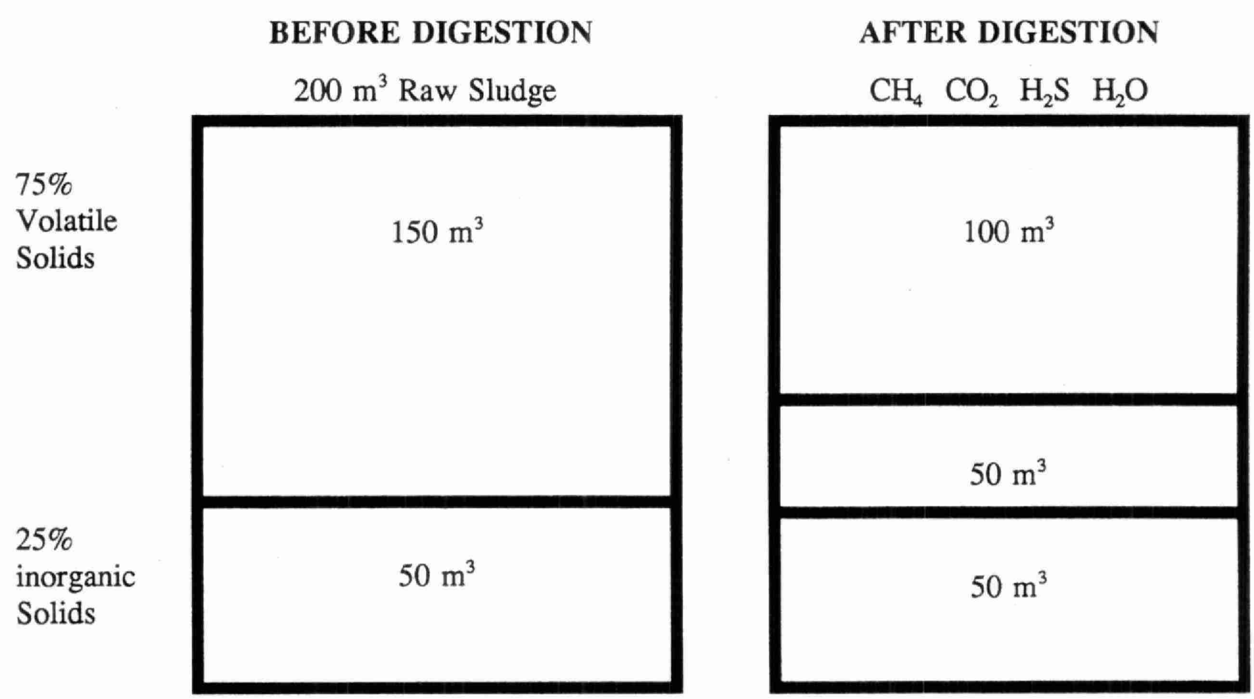
$$= \frac{0.68 - 0.43}{0.68 - (0.68 \times 0.43)} \times 100\%$$

$$= \frac{0.25}{0.39} \times 100\%$$

$$= 0.64 \times 100\%$$

$$= 64\%$$

What is actually happening in the calculation of the percent reduction of volatile matter may be visualized by the following example. Start with 200 m^3 of raw sludge solids consisting of 75% volatile organic solids and 25% inorganic solids. After digestion, 100 m^3 of volatile matter has been converted to methane, carbon dioxide, and supernatant water containing solids, nitrogen, and a COD. The remaining digested sludge consists of 50 m^3 volatile solids and 50 m^3 of inorganic solids.



D. Computing Digester Loadings

Digester loadings are reported as kg of volatile matter per cubic metre of digester volume per day. The loading rate should be around 2.4 kg to 5.6 kg of volatile solids per cubic meter in a heated and mixed digester. For an unmixed or cold digester, the loading rate should not exceed 0.8 kg of volatile matter per cubic metre, assuming that each cubic meter contains approximately 8.0 kg of predigested solids.

A 10 m diameter and 7 m water depth digester has a raw sludge volume of 40 m^3 at 6.5% total solids and 68% volatile solids. It was determined that there were 1 768 kg of volatile solids added to the digester per day. Calculate the digester loading.

Example

$$Digester\ Loading = \frac{kg\ of\ volatile\ solids\ /d}{Volume\ of\ Digester\ (\ m^3\ )}$$

$$= \frac{1768\ kg\ volatile\ solids\ /d}{549.8\ m^3}$$

$$= 3.2\ kg\ /\ m^3\ .\ d\ of\ volatile\ solids$$

E. Volatile Solids Destroyed

The data is reported as kg of volatile solids destroyed per cubic meter of digester capacity per day. Using the same data from the previous example and starting from the beginning with 40 m^3 at 6.5% total solids, and 68% volatile solids assume a volatile solids reduction of 50%.

$$Volatile\ Solids\ Destroyed = \frac{Vr \times \%TS \times \%V \times \%R \times 1000\ kg/m^3}{Digester\ Volume\ (\ m^3\ )}$$

Where:

Vr	=	Volume of raw sludge per day
TS	=	Total Solids
V	=	Volatile
R	=	Reduction

$$Volatile\ Solids\ Destroyed = \frac{Vr \times \%TS \times \%V \times \%R \times 1000\ kg/m^3}{Digester\ Volume\ (\ m^3\ )}$$

$$= \frac{(\ 40\ m^3\ /\ d\ )\ (\ 0.065\ )\ (\ 0.5\ )\ (\ 1000\ kg/m^3\ )}{549.8\ m^3}$$

$$= \frac{884\ kg}{549.8\ m^3\ .\ d}$$

$$= 1.6\ kg/m^3\ .\ d$$

F. Computing Gas Production

Digester gas data should be recorded in cubic metres produced per day by the digestion system, as recorded daily from the gas meter. The carbon dioxide ($C0_2$) content should normally be tested once or twice a week. Any change of $C0_2$ concentration in the digester gas is an indicator of the operating condition of the digester. Good digester gas will have a CO_2 content of 30 to 35%. The volatile acid/alkalinity relationship will start to increase before the carbon dioxide (CO_2) content begins to climb. If the CO_2 content exceeds 42%, the digester is considered to be in poor condition and the digester gas is now close to the lower limit of flammability (44 to 45% of $C0_2$ by volume).

Gas production should range between 0.44 m^3 and 0.75 m^3 per kg of volatile solids destroyed in the digesters.

Example

A digester produces 525 m^3/d of gas. If the mass of the volatile solids destroyed per day was 884 kg,calculate the gas production per kg of destroyed volatile solids.

Solution

$$\text{Gas Production} = \frac{\text{Gas Produced } (m^3/d)}{\text{Destroyed Volatile Solids } (kg/d)}$$

$$= \frac{525\ m^3/d}{884\ kg/d}$$

$$= 0.59\ m^3/kg$$

SECTION G

WORKING SECTION FOR ANAEROBIC DIGESTION PROCESS

1. A sludge sample taken from a primary digester was tested and the following was found:

Total Alkalinity	2 500 mg/L
Volatile Acids	270 mg/L

Calculate the volatile acid/alkalinity ratio.

2. During a 24 h period 15 000 L of raw sludge with a total solids concentration of 5.7% and a volatile solids content of 71% was pumped to a digester. What is the mass of the volatile solids pumped?

3. Calculate the reduction of volatile solids in a digester if the raw sludge volatile solids was 69% and the digested sludge volatile solids was 44%?

4. What is the organic loading of a digester with 600 m^3 volume, receiving a raw sludge that has a volatile solids content of 62% and a total solids concentration of 5.9%? The volume of raw sludge pumped is 50 m^3 daily.

5. Using the data from Question 4, calculate the amount of volatile solids destroyed if the volatile solids reduction is 49%.

6. 900 m^3 of digester gas is burned daily in the heat exchanger boiler, while 150 m^3 of gas is burned at the waste gas burner. If 1 750 kg of volatile solids are destroyed daily, what is the gas production (m^3/kg)?

7. A sludge digestion facility has the following characteristics:

a)	Digester volume	2 250 m^3
b)	Raw sludge pumped daily	140 m^3
c)	Raw sludge total solids	6%
d)	Raw sludge volatile solids	67%
e)	Digested sludge total solids	5.7%
f)	Digested sludge volatile solids	51%
g)	Gas produced daily	1 300 m^3/d

Determine the following using the data given.

i) Detention time in days?

ii) Digester Organic Loading?

iii) % reduction of volatile solids?

iv) Volume of gas produced per kg of volatile solids destroyed?

SECTION H

EXAMPLE CALCULATIONS FOR SURFACE WATER

FILTER LOADING RATE

The "filter loading rate" is expressed as L or m^3 of water applied to each m^2 of surface area. This could also be described as the amount of water flowing down through each m^2 of filter surface. Filter design loading rates are expressed as $m^3/m^2 \cdot h^{-1}$ and $L/m^2 \cdot s^{-1}$.

$$\textit{Filter Loading Rate} = \frac{\textit{Flow}\ (m^3/d)}{\textit{Filter Area}\ (m^2)}$$

NOTE: Design loading rates for filters are expressed in US gals at present. Using conversion factors to obtain S.I. units is necessary when studying American designed filters. Typical loading rates are shown below:

Rapid sand filter	=	1.36 $L/m^2 \cdot s^{-1}$, (2 US gpm/ft^2)
Dual Media	=	0.136 - 0.272 $L/m^2 \cdot s^{-1}$, (0.2-0.4 US gpm/ft^2)
Multi Media	=	3.41 - 6.82 $L/m^2 \cdot s^{-1}$, (5-10 US gpm/ft^2)

Example

A rapid sand filter is 10 m wide and 15 m long. If the flow through the filter is 17 630 m^3/d what is the filter loading rate in $L/m^2 \cdot s^{-1}$? First, convert the flow to L/s.

$$\textit{Flow} = \frac{17630\ m^3}{d} \times \frac{1000\ L}{m^3} \times \frac{86400\ s}{d} = \frac{204\ L}{s}$$

Then express the filter loading rate mathematically as:

$$\textit{Filter Loading Rate} = \frac{\textit{Flow}\ (m^3/d)}{\textit{Filter Area}\ (m^2)}$$

$$= \frac{204\ L/s}{150\ m^2}$$

$$= 1.36\ L/m^2 \cdot s^{-1}$$

FILTER BACKWASH RATE

There are two methods that may be used to calculate the filter backwash rate:

a) $$\textit{Filter Backwash Rate} = \frac{Flow\ (m^3/d)}{Filter\ Area\ (m^2)}$$

b) $$\textit{Filter Backwash Rate} = \frac{meters\ of\ water\ rise}{hours}$$

NOTE: As with filter loading rates, filter backwash rates are also expressed in U.S. gals at present. Rates are shown below:

Minimum	=	$10.2\ L/m^2 \cdot s^{-1}$, (15 US gpm/ft^2)
Maximum	=	$15.3\ L/m^2 \cdot s^{-1}$, (22.5 US gpm/ft^2)

This is equivalent to a rise in the water level of 36.67 m/h (2 ft/min) to 55.0 m/h (3 ft/min).

EXAMPLE 1

A rapid sand filter is 10 m wide and 1 m long. If backwash water is flowing upward at a rate of 1.56 m^3/s, what is the backwash rate in $L/m^2 \cdot s^{-1}$?

$$Flow = \frac{1.56\ m^3}{s} \times \frac{1000\ L}{m^3} = 1560\ L/s$$

Therefore, there are 1 560 L/s flowing upward through a filter with a surface area of 120 m^2. This can be written mathematically as:

$$\textit{Filter Backwash Rate} = \frac{Flow\ (L/s)}{Filter\ Area\ (m^2)}$$

$$= \frac{1560\ L/s}{120\ m^2}$$

$$= 13\ L/m^2 \cdot s^{-1}$$

EXAMPLE 2

A mixed-media filter is 8 m wide and 11 m long. If the filter receives a backwash flow of 84 000 m^3/d, what is the filter backwash flow rate in $L/m^2 \cdot s^{-1}$?

As in the last example, first convert the backwash flow to L/s.

$$Flow = \frac{84000\ m^3}{d} \times \frac{1000\ L}{m^3} \times \frac{86400\ s}{d} = \frac{972.22\ L}{s}$$

$$Filter\ Backwash\ Rate = \frac{Flow\ (\ L\ /s\ )}{Filter\ Area\ (\ m^2\ )}$$

$$= \frac{972.22\ L\ /s}{(\ 8\ m\ )\ (\ 11\ m\ )}$$

$$= \frac{972.22\ L\ /s}{88\ m^2}$$

$$= 11.05\ L\ /m^2\ .\ s^{-1}$$

Filter backwash rates, as noted earlier, are sometimes expressed in terms of vertical rise of water in a time interval measured in hours, for example, metres per hour (m/h). The units of measure are directly related to each other as shown by the following proof:

$$Filter\ Backwash\ Rate = 11.05\ L\ /m^2\ s\ .\ s^{-1}$$

$$= \frac{11.05\ L\ /m^2}{s} \times \frac{3600\ s}{h} \div \frac{1000\ L}{m^3}$$

$$= \frac{39.672\ m^3\ /m^2}{h}$$

$$= 39.672\ m/h$$

For simplification, a conversion factor can be extracted from the above proof.

$$\frac{3600\ s}{h} \div \frac{1000\ L}{m^3} = \frac{3.6\ m^3 \,.\, s}{L \,.\, h}$$

Then by substitution back into the proof:

$$\frac{11.05\ L}{m^2 \,.\, s} \times \frac{3.6\ m^3 \,.\, s}{L \,.\, h} = \frac{39.672\ m^3\ /m^2}{h} = 39.672\ m/h$$

SECTION I

WORKING SECTION FOR SURFACE WATER

1. A rapid sand filter is 5 m wide and 10 m long. If the backwash water flow rate is 55 600 m^3, determine the filter backwash rate in m/h?

2. What is the filter backwash rate in $L/m^2 . s^{-1}$ corresponding to a filter backwash rate of 37 m/h?

3. During operation of a multi media sand filter, the operator measured the flow rate to be 14.4 m/h. Express this filter flow rate in $L/m^2 . s^{-1}$.

4. A rapid sand filter is 4 m wide and 7 m long. If the flow through the filter is 3 300 m^3/d what is the filter loading rate?

   a) $L/m^2 . s^{-1}$

   b) m/h

SECTION J

CHEMICAL FEEDING & PREPARATION OF STOCK SOLUTIONS

SOLUTIONS

A solution consists of two components, a **solvent** which is the dissolving medium and a **solute** which is the substance dissolved. The solute is dispersed as molecules and ions and the distribution of the solute is homogeneous throughout the solution. A common example of solvent and solute is water and sugar.

A **concentrated** solution is one which contains a relatively large amount of solute per unit volume of solution. A **dilute** solution is one which contains a relatively small amount of solute per unit volume of solution. The words "strong" and "weak" should not be used when referring to the concentration of a solution. Strong and weak are terms that are more properly used to describe the chemical activity of a substance.

PERCENT SOLUTIONS

The concentration of a chemical solution may be described as a percent solution by volume (% w/v).

Examples:
- i) 1% chlorine solution
- ii) 0.5% alum solution w/v
- iii) 3% bicarbonate solution by volume

This refers to the mass of solute in a given volume of solution.

$$\chi\ \%\ solution = \frac{\chi\ gm\ solute}{100\ ml\ solution}$$

Examples:

i) 100 ml of a 1% calcium hypochlorite solution contains 1gm of calcium hypochlorite

$$1\%\ calcium\ hypochlorite\ solution = \frac{1\ gm\ calcium\ hypochlorite}{100\ ml\ calcium\ hypochlorite\ solution}$$

ii) 100 ml of a 0.5% alum solution contains 0.5 gm of alum sol'n

$$0.5\%\ alum\ solution = \frac{0.5\ gm\ alum}{100\ ml\ alum\ solution}$$

Sample Problem

Q: How many gm of bicarbonate are contained in 1 L of 3% bicarbonate solution?
A:

a) $$3\%\ \textit{bicarbonate solution} = \frac{3\ gm\ bicarbonate}{100\ ml\ solution}$$

b) $$\frac{3\ gm\ bicarbonate}{100\ ml\ solution} \times \frac{1000\ ml}{1\ L} = \frac{30\ gm\ bicarbonate}{L\ solution}$$

PERCENT SOLUTION BY WEIGHT

The concentration of a chemical solution may also be described as percent solution by weight (% w/w).

Examples:
- i) 0.2% alum solution by weight
- ii) 4% iron solution w/w
- iii) 0.005% caffeine solution by mass

This refers to the mass of solute in a given mass of solution.

$$\chi\ \%\ w/w\ solution = \frac{\chi\ gm\ solute}{100\ gm\ solution}$$

Examples: i) 100 gm of a 0.2% alum solution by weight contains 0.2 gm of alum

$$0.2\%\ w/w\ solution = \frac{0.2\ gm\ alum}{100\ gm\ solution}$$

ii) 100 gm of a 4% iron solution w/w contains 4 gm of iron.

$$4\%\ w/w = \frac{4\ gm\ iron}{100\ gm\ solution}$$

Sample Problem:

Q: How many g of caffeine are in 2 kg of a 0.005% caffeine solution by mass?

A:

a) $$0.005\%\ solution = \frac{0.005\ gm\ caffeine}{100\ gm\ solution}$$

b) $$\frac{0.005\ gm\ caffeine}{100\ gm\ solution} \times \frac{2000\ gm}{2\ kg} = \frac{0.10\ gm\ caffeine}{2\ kg\ solution}$$

Solution Preparation - Jar Tests

Jar tests are used to determine correct chemical dosages for such chemicals as alum, ferric chloride, or polymers. These chemicals are utilized in water treatment for coagulation and flocculation of colloidal particles and are used in wastewater treatment for chemical precipitation of phosphorous. The jar test simulates, on a small scale, the activities going on in the full scale treatment process. Varying amounts of the chemicals are compared to each other to see which chemical and dosage, best accomplishes the desired results.

Stock solutions of coagulants, coagulant aids and other quantities suitable for use in the jar tests can be measured accurately and conveniently.

When making stock solutions from dry chemicals, a very straight forward approach is used. Dissolve 1 gram of solute in 1 litre of water to obtain a 1 g/L solution (0.1%). Using the solution is easy because 1 gram of solute is contained in 1 litre solvent; therefore 1 mg of solute is contained in 1 mL of solvent. When a jar test requires dosages of solution, simply fill a pipet to the required dosage and the proper mass of chemical will be present in the contained volume of the solution.

EXAMPLE:

One gram of soda ash is contained in one litre of distilled water. We now have a 1 g/L solution of soda ash. A jar test requires dosages of 5 mg/L, 10 mg/L, 15 mg/L, 20 mg/L, 25 mg/L and one jar is a blank. How many mL of soda ash solution are required for each dosage?

1 g/L soda ash solution	=	1 mg of soda ash/mL of solution
5 mg of soda ash	=	5 mL of solution
Req'd dosages	=	5 mg/L, 10 mg/L, 15 mg/L, 20 mg/L, 25 mg/L
mL of solution	=	5 mL, 10 mL, 15mL, 20 mL, 25 mL

Remember that the number of milligrams of soda ash in the stock solution remains constant but is diluted up to 1L with distilled water. The dosage is now expressed as mg/L.

To prepare solutions from liquid concentrates the following information is needed:

a) % by wt.
b) specific gravity (S.G.)

The concentration and S.G. are usually found on the product label.

Example: alum solution contains 48.5% alum by weight (w/w) and has a specific gravity of 1.35. To prepare a 1 gm/L solution from the concentrated alum, we need to find out how many mL of concentrate contains 1 gram of pure dry alum.

1 mL of concentrated solution contains 1.35 x 0.485 gm of dry alum = 0.65 g of dry alum

Therefore the number of mL corresponding to 1 gm of dry alum $= \frac{1\ gm}{0.65\ gm/mL} = 1.54\ ml$

1.54 mL of concentrated alum contains 1 gram of alum. To make a 1 gm/L solution of alum simply dilute 1.54 mL of concentrated solution to one litre with distilled water. Dosages can now be applied to jar tests as described earlier in the section on Dry Chemical Solution Preparation.

CHEMICAL FEEDING

Water and Wastewater Operations

Jar test are necessary to determine the chemical, the chemical dosage and the point of application best suited to the characteristics of the water/wastewater to be treated. Since physical and chemical characteristics of raw water/wastewater vary, jar tests must be carried out frequently and plant processes adjusted accordingly.

Chemicals may be used in either dry or liquid form. When using dry chemicals the feeder is usually calibrated in g/min. When using liquid chemicals the feeder is usually calibrated in mL/min. The following is a detailed approach to establishing feed rates for chemicals.

EXAMPLE

A daily flow of 16 000 m^3/d requires a dosage of 13 mg Fe^{+++}/L [fed as ferric chloride] for phosphorous removal. Calculate the flow rate in mL/min.

Ferric chloride	=	1.67 kg/L
Fe^{+++}	=	13.7% by mass in solution.

Step 1. Determine the mass of solution required (kg/d)

$$\textit{Solution required} = \frac{\textit{Dosage} \times \textit{Flow}}{\textit{Decimal fraction of active ingredients}}$$

$$= \frac{(13\ kg/\ 1000\ m^3)\ (16000\ m^3\ /d)}{0.137}$$

$$= 1518.25\ kg\ FeCl_3\ solution\ /d$$

Step 2. Determine volume (L/d) of solution required.

1 litre of solution has a mass of 1.67 kg. It is necessary to divide the total mass of solution by the specific gravity of the solution.

$$\textit{Volume of solution} = \frac{\textit{mass of } FeCl_3 \textit{ solution}}{\textit{specific gravity}}$$

$$= \frac{kg/d}{kg/l}$$

$$= \frac{1518.25\ kg/d}{1.67\ kg/L}$$

$$= 909.1\ L\ FeCl_3\ solution\ /d$$

Step 3. Now we convert the volume of solution required into the flow rate by the following conversion factors:

$$\textit{Flow Rate} = \frac{909.1\ L\ FeCl_3\ sol'n}{d} \times \frac{1000\ mL}{1\ L} \div \frac{1440\ \mathrm{min}}{d}$$

$$= 631.32\ mL\ FeCl_3\ solution\ /\mathrm{min}$$

<u>**EXAMPLE**</u>

A water plant with a daily flow of 1 700 m^3 doses at 55 mg/L with a 48.5% (w/w) liquid alum solution. What is the feed rate in mL/min?

Data: Flow of 1.7 x 1000 m^3/d
48.5% alum by weight as active ingredient
1.34 g/cm^3 specific gravity

$$\textit{Mass of solution required} = \frac{(\ 55\ kg\ /1000\ m^3\ )\ (\ 1.7 \times 1000\ m^3\ /d\ )}{0.485}$$

$$= 192.8\ kg/d$$

$$Volume\ of\ solution = \frac{192.8\ kg/d}{1.34\ kg/L}$$

$$= 143.9\ kg\ /L$$

$$Flow\ Rate = \frac{143.9\ L\ FeCl_3\ sol'n}{d} \times \frac{1000\ mL}{1\ L} \div \frac{1440\ \mathrm{min}}{d}$$

$$= 99.9\ mL\ FeCl_3\ solution\ /\mathrm{min}$$

It is important to mention that feed rates are properly expressed as mL/s but using mL/min is convenient to calibrate and measure. To obtain mL/s simply divide mL/min by 60 s/min as shown with the following example.

$$Flow\ Rate = \frac{99.9\ mL}{\mathrm{min}} \div \frac{1\mathrm{min}}{60\ s}$$

$$= 1.665\ mL\ /s$$

CALCULATION OF FEED RATES USING A FORMULA

An alternate method of calculating feed rates in mL/min is through the use of a formula that takes into account all variables including chemical concentration, optimum dosage, plant flow and specific gravity. Both methods are equally valid. However, the formula method may be more convenient for practical applications.

$$mL/\text{min} = \frac{dosage\ (\ mg/L\ ) \times flow\ (\ m^3/d\ ) \times 1000\ mL/L}{1000 \times \%\ active\ chemical\ as\ decimal\ fraction \times specific\ gravity \times 1440\ \text{min}/d}$$

We can simplify the feed rate formula. Using the previous example, determination of the alum feed rate, the calculation can be shown as:

$$mL/\text{min} = \frac{dosage\ (\ mg/L\ ) \times flow\ (\ m^3/d\ ) \times (\ 0.694\ )}{1000 \times \%\ active\ chemical\ as\ decimal\ fraction \times specific\ gravity}$$

$$= \frac{(\ 55\ mg/L\ )\ (\ 1.7 \times 1000\ m^3\ /d\ )\ (\ 0.694\ )}{(\ 0.485\ )\ (\ 1.34\ kg/L\ )}$$

$$= 99.8\ mL/\text{min}$$

SECTION K

WORKING SECTION FOR STOCK SOLUTIONS AND CHEMICAL FEED RATES

1. How many mL of ferric chloride are needed to prepare 1 000 mL of a 1 gm/L solution of ferric chloride if the concentrated solution is 42.3% by weight and the specific gravity is 1.42?

2. How many mL of alum are required to make up 1 L of a 1 gm/L solution for jar tests if the alum is 48% by weight and the specific gravity is 1.34?

3. In a wastewater treatment plant with an average daily flow of 11 250 m^3/d, alum is being used for phosphorous removal at a dosage of 450 mg/L. What alum flow rate, measured in mL/min is needed? (USE DETAILED METHOD FOR CALCULATION)

DATA: Liquid alum has a specific gravity of 1.35 kg/L
Liquid alum contains 48% by weight alum as
$Al_2(SO_4)_3 \cdot 14H_2O$

4. In a water treatment plant both alum and activated silica are being used in the coagulation stage to help precipitate the colloidal suspensions. Jar tests indicated that 50 mg/L alum and 5.5 mg/L activated silica is the optimum dosage. Calculate, using the formula, the feed rate needed for each chemical in mL/min.

DATA:

Flow	1 000 m^3/d
Liq Alum Specific gravity	1.35 kg/L
Liq Alum contains	48.5% $Al_2(SO_4)_3 \cdot 14H_2O$
Act Silica Specific gravity	1 kg/L
Act Silica contains	1% solution

5. A plant has an average daily flow of 17 750 m^3/d and is using ferric chloride for phosphorus removal at 15 mg/L Fe^{+++}. What feed rate of ferric chloride is needed in:

a) mL/min b) L/d

DATA:	Liq. $FeCl_3$ specific gravity	1.4 kg/L
	$FeCl_3$ contains	14.0% (w/w) Fe^{+++}
	$FeCl_3$ contains	41.5% (w/w) $FeCl_3$

6. The dry alum dosage rate is 12 mg/L at a water treatment plant. The flow rate at the plant is 13 500 m^3/d. How many kilograms per day of alum are required?

APPENDIX 1

CONVERSION FACTORS

CUSTOMARY UNIT (U.S.)		MULTIPLIER		SI UNIT
acre	X	4 046.9	->	m^2
	<-	2.471 1 x 10^{-4}	X	
acre	X	0.404 69	->	ha
	<-	2.471 1	X	
acre-ft	X	1 233.5	->	m
	<-	8.107	X	
Btu	X	1.055	->	kJ
	<-	0.947 8	X	
Btu/h/sq ft	X	3.154	->	J/m^2 .s
	<-	0.317 0	X	
Btu/lb	X	2.326	->	kJ/kg
	<-	0.430 0	X	
cfm	X	4.719 x 10^{-4}	->	m^3/s
	<-	2 119	X	
cfs	X	0.028 32	->	m^3/s
	<-	35.315	X	
cfs/acre	X	0.069 97	->	* m^3/ha .s
	<-	14.29	X	
cu ft	X	0.028 32	->	m^3
	<-	35.315	X	
cu ft	X	28.32	->	* L
	<-	0.035 315	X	

CUSTOMARY UNIT (U.S.)		MULTIPLIER		SI UNIT
cu in	X <-	16.39 0.061 02	-> X	cm^3
cu yd	X <-	0.764 6 1.308	-> X	m^3
°F	X <-	0.555 (°F - 32) 1.8 (°C) + 32	-> X	°C
°C	+ <-	273 273	-> -	K°
ft	X <-	0.304 8 3.281	-> X	m
ft-lb	X <-	1.356 0.737 6	-> X	J
gal	X <-	3.785 0.264 2	-> X	* L
gal	X <-	0.003 785 264.2	-> X	m^3
gpd/acre	X <-	0.009 353 106.9	-> X	* m^3/ha .d
gpd/ft	X <-	0.012 42 80.52	-> X	* m^3/m .d
gpd/sq ft	X <-	0.030 74 24.55	-> X	* m^3/m^2 .d
gpm	X <-	6.308×10^{-5} 1.585×10^3	=>	m^3/s
pm	X <-	0.063 08 15.85	-> X	* L/s

CUSTOMARY UNIT (U.S.)		MULTIPLIER		SI UNIT
gpm/sq ft	X	0.679 02	->	* L/m^2 .s
	<-	1.473	X	
hp	X	0.745 7	->	kW
	<-	1.341	X	
hp-h	X	2.685	->	MJ
	<-	0.372 5	X	
in	X	25.400	->	mm
	<-	0.039 37	X	
lb (force)	X	4.448	->	N
	<-	0.224 8	X	
lb (mass)	X	0.453 6	->	kg
	<-	2.205	X	
lb/day/acre-ft	X	0.367 7	->	* g/m^3 .d
	<-	2.719 6	X	
lb/l000 cu ft	X	16.02	->	g/m^3
	<-	0.062 43	X	
lb/day/acre	X	0.112 1	->	* g/m^3 .d
	<-	8.922	X	
lb/day/cu ft	X	10.02	->	* kg/m^3 .d
	<-	0.062 43	X	
lb/day/sq ft	X	4.883	->	* kg/m^2 .d
	<-	0.204 8	X	
lb/ft	X	1.488	->	kg/m
	<-	0.672 0	X	
lb/mil gal	X	0.119 8	->	g/m^3
	<-	8.344	X	

CUSTOMARY UNIT (U.S.)		MULTIPLIER		SI UNIT
mil gal	X	3 785	->	m^3
	<-	2.642 x 10^{-4}	X	
mgd	X	3 785	->	m^3/d
	<-	2.642 x 10^{-4}	X	
mgd	X	0.043 8	->	m^3/s
	<-	22.83	X	
mgd/acre	X	1.082 x 104	->	m^3/m^2 .s
	<-	9.238 x 104	X	
mile	X	1.609	->	km
	<-	0.621 4	X	
ppm (by weight)		essentially	->	* mg/L
	<-	essentially		
psf	X	0.047 88	->	kN/m^2
	<-	20.89	X	
psf	X	4.882	->	kg/m^2
	<-	0.204 8	X	
psi	X	6.895	->	kN/m^2
	<-	0.145 0	X	or KPa
psi	X	0.070 3	->	* kgf/cm^2
	<-	14.22	X	
sq ft	X	0.092 9	->	m^2
	<-	10.76	X	
sq in	X	645.2	->	mm^2
	<-	0.001 55	X	
sq miles	X	2.590 0	->	km^2
	<-	0.386 1	X	

CUSTOMARY UNIT (U.S.)		MULTIPLIER		SI UNIT
yard	X <-	0.914 4 1.094	-> X	m
mgd	X <-	4.381×10^{-2} 22.830	-> X	m^3/s
gpm	X <-	5.450 0.183 5	-> X	* m^3/d
cfs	X <-	28.450 0.035 15	-> X	* L/s
cu ft/mil gal	X <-	0.007 482 133.7	-> X	* L/m^3
lb/mil gal	X <-	0.119 8 8.344	-> X	g/m^3
cfm/lin ft	X <-	1.549 0.645 8	-> X	* L/m .s
sq ft/ft	X <-	0.304 8 3.281	-> X	m^2/m
gpd/lin ft	X <-	0.012 42 80.53	-> X	* m^3/m .d
gpd/lin ft	X <-	1.437×10^{-4} 695 8	-> X	* L/m .s
ft/h	X <-	0.084 67 11.810	-> X	mm/s
ft/h	X <-	0.304 8 3.281	-> X	* m/h
lb/day/sq ft	X <-	4.883 0.204 8	-> X	* kg/m^2 .d

CUSTOMARY UNIT (U.S.)		MULTIPLIER		SI UNIT
lb/day/sq ft	X <-	0.056 51 17.70	-> X	$g/m^2 .s$
lb/day/l000 sq ft	X <-	4.883 0.204 8	-> X	* $g/m^2 .d$
lb/day/lb	X <-	1.00 1.00	-> X	* kg/kg .d
cu ft/lb	X <-	0.062 43 16.02	-> X	m^3/kg
cu ft/gal	X <-	0.133 7 7.481	-> X	m^3/m^3
cfm	X <-	0.417 9 2.119	-> X	* L/s
cfm	X <-	4.719×10^{-4} 2 119	-> X	m^3/s
lb/h/cu ft	X <-	16.02 0.062 43	-> X	* $kg/m^3 .h$
lb/h/cu ft	X <-	.004 450 224.7	-> X	$g/m^3 .g$
cfm/l000 cu ft	X <-	0.016 67 60	-> X	* $L/m^3 .s$
hp/l000 cu ft	X <-	26.34 0.037 97	-> X	W/m^3
lb/acre/day	X <-	1.121 0.892 2	-> X	* kg/ha .d
lb/day	X <-	0.453 6 2.205	-> X	* kg/d

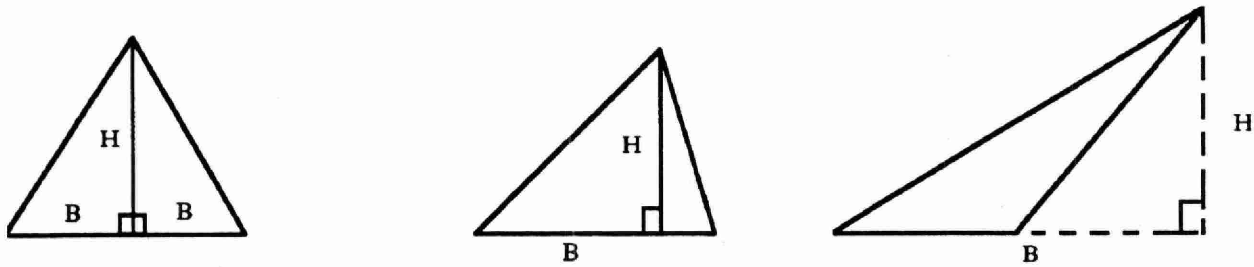
CUSTOMARY UNIT (U.S.)		MULTIPLIER		SI UNIT
cu ft/capita	X <-	28.32 0.035 31	-> X	L/person
lb/yr/sq ft	X <-	4.883 0.204 8	-> X	* kg/m^2 .y
sq ft/cap	X <-	0.092 90 10.76	-> X	m^2/person
lb/h/sq ft	X <-	28.32 0.035 31	-> X	* kg/m^2 .h
lb/h/sq ft	X <-	.356 0.737 3	-> X	g/m^2 .s
cu ft/h/sq ft	X <-	0.304 8 3.281	-> X	* m^3/m^2 .h
cu ft/h/sq ft	X <-	0.084 63 11.82	-> X	* L/m^2 .s
gpm/sq ft	X <-	0.679 02 1.473	-> X	L/m^2 .s
lb/lb	X <-	1 000 10	-> X	g/kg
gpm/lin ft	X <-	0.207 0 4.832	-> X	* L/m .s
Btu/lb	X <-	2.326 0.430 0	-> X	kJ/kg
lb/h	X <-	0.126 0 7.937	-> X	g/s
lb/h	X <-	0.453 6 2.205	-> X	* kg/h

* **Not strictly SI**

APPENDIX 2
GEOMETRY

AREAS

1. Triangle

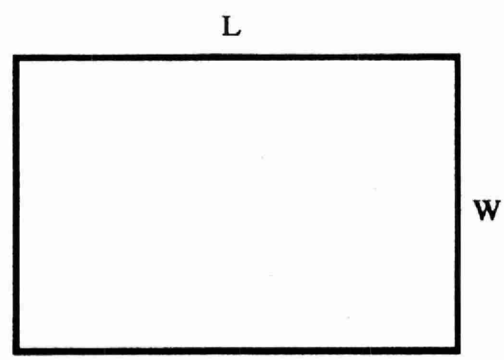


The area of a triangle:

$$Area = \frac{1}{2}\ Base \times Height$$

$$= \frac{1}{2}\ B \times H$$

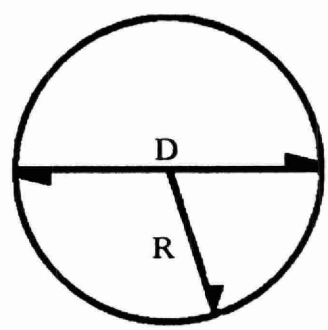
2. Rectangle



The area of a rectangle

$$Area = Length \times Width$$

3. Circle



D = Diameter
R = Radius
C = Circumference
π = 3.1416

The area of a circle

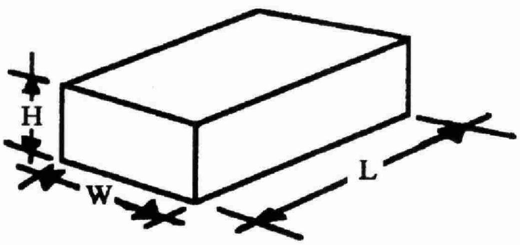
$$Area = \pi R^2 \quad OR \quad \pi \frac{D}{4}$$

GEOMETRY

VOLUMES

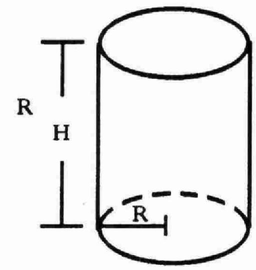
Rectangle

$$Volume = L \times W \times H$$



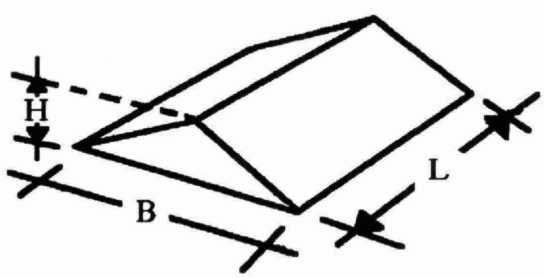
Cylinder

$$Volume = \pi R^2 H \text{ (area of base } \times \text{ height)}$$



Triangle

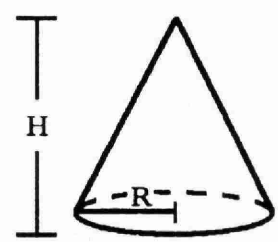
$$Volume = \frac{1}{2} B \times H \times L$$



Cone

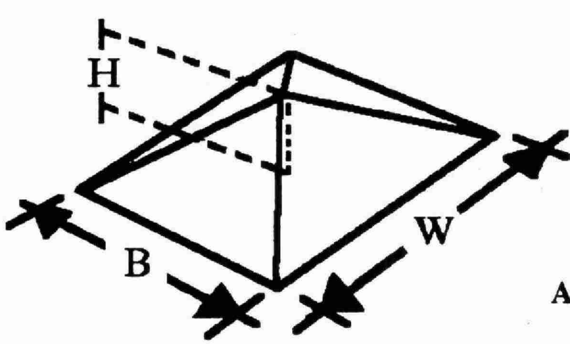
$$Volume = \frac{\Pi R^2 H}{3}$$

$$= \frac{1}{3} \text{ area of base } \times \text{ height}$$



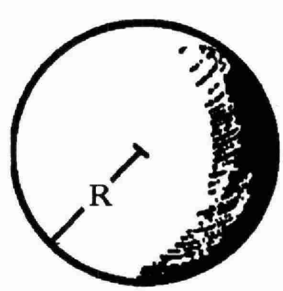
Pyramid

$$Volume = \frac{1}{3} B \times H \times W$$



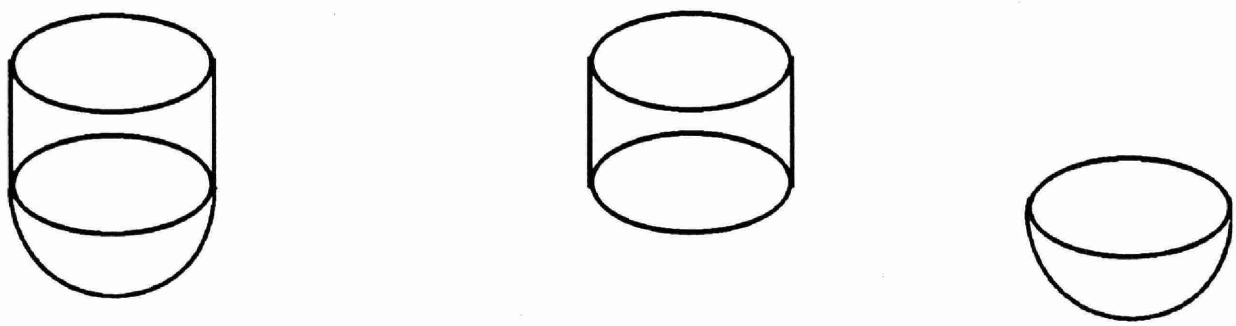
Sphere

$$Volume = \frac{4}{3} \Pi R^3$$



Occasionally it is necessary to calculate the volume of a tank that consists of two distinct shapes. In other words, there is no "representative surface area" for the entire shape. In this case, the volumes should be calculated separately, then the two volumes added together. The diagrams below illustrate this method.

ROUND BOTTOM TANK = CYLINDER + HALF SPHERE



APPENDIX 3

GUIDE TO THE USE Of SI
(Adapted from "Manual of Practice No. 6
Water Pollution Control Federation, 1976)

1. In writing the symbols in SI, Roman (upright) type, usually lower case, is used for symbols of units. If the symbol is derived from a proper name, capital Roman type is used. Symbols are not followed by a period and are not changed in the plural.

2. Units that are internationally recognized and used should not be lightly discarded even though the unit in question is not an SI unit or a preferred multiple of an SI unit.

3. Multiples and submultiples involving the factor 1 000 should be used if practical.

4. The product of two or more units is preferably indicted by a dot. The dot may be dispensed with when there is no risk of confusion with another unit symbol. For example, moment of a force: N.m, Nm.

5. The division of two units is shown in the following example.

$$\text{Velocity} = \text{m/s}, \frac{\text{m}}{\text{s}}, \text{m.s}^{-1}$$

6. The solidus (/) must not be repeated on the same line; in the example of acceleration, m/s^2 or $m.s^{-2}$, but not m/s/s.

7. In writing numbers having four or more digits, the digits should be placed in groups of three separated by a space counting both to the left and to the right of the decimal point. In the case of a four digit number the spacing is optional. For example:

1,532	is written	1 532 or 1532
132,541,816	is written	132 541 816
983,769.81678	is written	983 769.816 78

8. Prefix symbols are printed in Roman type without spacing between the prefix symbol and the unit symbol.

9. Double prefixes should not be used, for example, use GW (gigawatt), not kMW.

10. An exponent attached to a symbol containing a prefix indicates that the multiple or submultiple of the unit is raised to the power expressed by the exponent. For example:

$$1\ cm^3 = (10^{-2}\ m)^3 = 10^{-6}\ m^3$$

$$1\ cm^{-1} = (10^{-2}\ m)^{-1} = 102\ m^{-1}$$

11. When writing the symbols of a unit the time symbol is preferably placed last. For example, use $m^3/ha\ .s^{-1}$ and not $m^3/s\ .ha$.

12. In rounding numbers by dropping the digits that are not significant, if the digit 6, 7, 8, or 9 is dropped, then the preceding digit is increased by one unit; if, on the other hand, the digit 0, 1, 2, 3, or 4 is dropped, the preceding digit is not altered. if the digit 5 is dropped, the preceding digit is rounded to the nearest even number.

13. The unit of length is spelled **metre**.

APPENDIX 4

ANSWERS TO PROBLEMS

SECTION B

1.		72 m^2
2.		177 m^2
3.		144 m^3
4.		577 m^3
5.		.66 m^3 or 660 L
6.		1.2 L/s, 103.7 m^3/d
7.		1.5 m^3
8.		25 d, 6 h
9.		5.7 h or 5 h 42 min
10.	90 kg	
11.	0.47 mg/L or 1.3 kg/d	

12.	1 kg	2 kg	4 kg	10 kg	500 g				
		4 kg	8 kg	16 kg	40 kg	2 kg			
		20 kg	40 kg	80 kg	200 kg		10 kg		
		500 g	1 kg	2 kg	5 kg	250 g			
		200 mg		400 mg		800 mg		2 g	100 mg

13.	1	2	5	20	0.4		
		0.2	0.4	1	4	0.08	All Figures
		0.1	0.2	0.5	2	0.04	expressed
		5	10	25	100	2	mg/L

14. a) 86.6% b) 13.4%

15. 540 kg

16. 25 kg, 25 L

Extra Problems

1. 4 m^3
2. 3.5 m^3/d
3. 630 kg H_20
   225 kg C
   45 kg $Al_2\ S0_4$
4. 22.5 m^3 or 22 500 L
5. 864 kg
6. 14.4 mg/L
7. 486 L/d sol'n

SECTION C

1. 140 m^2
2. 154 m^2
3. 48 m^3
4. 1 021 m^3
5. 1.1 L/s, 95 m^3/d
6. 1 800 L or 1.8 m^3/d
7. 25 d
8. 1.56 $m^3/,s$, 1 560 L/s
9. 6 h (4 fills a day)
10.

1 kg	2 kg	4 kg	10 kg	500 g	
4 kg	8 kg	16 kg	40 kg	2 kg	
20 kg	40 kg	80 kg	200 kg	10 kg	
500 g	1 kg	2 kg	5 kg	250 g	
200 mg	400 mg		800 mg	2 g	100 mg

11. 50 kg $C1_2$

12.

1	2	5	20	0.4	
0.2	0.4	1	4	0.08	All Figures
0.1	0.2	0.5	2	0.04	expressed
5	10	25	100	2	mg/L

13. 0.7 mg/L, 1.9 kg Cl_2 /d

EXTRA PROBLEMS

1. $357\ m^3$
2. a) 133.3 L/s
   b) 11 520 m^3/d
3. No; the calculated flow is 1 036.8 m^3/d
4. 8.4 kg Cl_2 /d
5. a) 40%
   b) 94%

SECTION E

1. 3 000 mg/L
2. 540 kg BOD_5
3. 0.5
4. 5 mg 0^2 h/g
5. $38.84\ m^3$
6. MLSS 2 364 mg/L SVI 88.8
7. SS Concentration 4.8 mg/L
8. 6 810 kg
9. 2 730 kg
10 3 154 kg
11. 3.9 d

SECTION G

1. 0.108
2. 607 kg
3. 63.8% reduction
4. 3.05 $kg/m^3/d$
5. 1.5 $kg/m^3/d$
6. 0.6 m^3/kg
7. i) 16 d
   ii) 2.5 $kg/m^3/d$
   iii) 48.8%
   iv) 0.45 m^3/kg

SECTION I

1. 46.3 m/h2
2. 10.3 $L/m^2 .s^{-1}$
3. 4 $L/m^2 .s^{-1}$
4. a) 1.36 $L/m^2 .s^{-1}$
   b) 4.9 m/h

SECTION K

1. 1.66 mL
2. 1.55 mL
3. 5 425 mL/min or 90.4 mL/s
4. Alum 53 mL/min
   Activated Silica 381.9 mL/min
5. 943 mL/min 1 357.9 L/d
6. 162 kg/d